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This is the National Science Teachers Association project report regarding curriculum development in science. The approach utilizes conceptual schemes as basic elements. The theoretical base for this approach is developed in detail, and the implications for the classroom teacher are carefully analyzed. Guidelines for implementing a curriculum development program are given which are directed toward action at the local level. The report is committed to a K-12 articulated program of curriculum development based on the concepts and processes of science. (GR)

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PROJECT REPORT

CONCEPTUAL SCHEMES IN SCIENCE:
A BASIS FOR CURRICULUM DEVELOPMENT

PA 24

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PREFACE

The Curriculum Committee of the National Science Teachers Association began in 1960 to develop its stance concerning curriculum development in the sciences. In 1962 a working paper on curriculum was discussed at the NSTA national convention in San Francisco. This document evoked enough interest in science curriculum development that a Conference on Science Concepts, under the chairmanship of Randall M. Whaley was arranged. A Subcommittee on Conceptual Schemes of the NSTA Curriculum Committee, chaired by Joseph D. Novak, was also established. The conferees in these two groups produced a statement on conceptual schemes and processes of science which was published as a major component of Theory Into Action . . . in Science Curriculum Development (NSTA, 1964).

Theory Into Action included several significant components:

1. "Toward a Theory of Science Education Consistent with Modern Science" by Paul DeHart Hurd.

2. "Conceptual Schemes and the Process of Science," a statement of a set of major conceptual schemes and major items in the process of science that can serve as the primary basis for science curriculum planning.

3. Suggestions for planning a local action program for implementing curriculum development in science.

This publication has elicited a great deal of response from the community of scientists and science educators. So provocative was the document, that the NSTA decided to undertake a supplementary project concerning science curriculum development.

In 1966, funds were provided by the U.S. Office of Education to support the work of an NSTA Conceptual Schemes Committee. The committee was comprised of: Charles R. Botticelli, Associate Professor of Biology, Boston University, chairman; Ted F. Andrews, Director of Science, Educational Research Council of Greater Cleveland; J.W. Buchta (deceased), Executive Secretary, American Association of Physics Teachers, Washington, D.C.; Paul F. Poehler, Jr., Assistant Superintendent of Schools, Lexington, Massachusetts; Chalmer J. Roy, Dean, College of Sciences and Humanities, Iowa State University, Ames; James A. Rutledge, Professor of Secondary Education, The University of Nebraska, Lincoln; Morris H. Shamos, Chairman, Department of Physics, New York University, New York City; Laurence E. Strong, Professor, Chemistry Department, Earlham College, Richmond, Indiana; Richard M. Whitney, Science Teacher, Roxbury Latin School, West Roxbury, Massachusetts; and charged with the responsibility of carrying forward the two major objectives of the project: (1) to provide a more detailed interpretation of the conceptual schemes of science and the major items in the process of science through analysis and expansion of the statements, together with any revisions that may appear to be desirable; and (2) to prepare some examples of ways in which pupil activities, devised or re-oriented, may be treated so as to make maximum contribution to a better understanding of the conceptual schemes and greater facility in the process of science, and to assist teachers in designing curriculum materials and showing ways in which they can be used in the classroom.

Assistance was given to the committee by John H. Woodburn and Janice A. Cutler, who provided copy for parts of this report, and by Albert F. Eiss, associate executive secretary, NSTA, who served as the staff liaison with the committee and contributed a chapter to the report.

The results of the work of the Conceptual Schemes Committee and the NSTA Curriculum Committee comprise this report and its Appendix.

Robert H. Carleton
Executive Secretary, NSTA

FOREWORD

"The National Science Teachers Association has as its central purpose the advancement and improvement of the teaching of science at all educational levels. Implicit in this purpose are concern for the curriculum and concern that the Association provide some active leadership in helping to establish criteria for sound curriculum development.

"The NSTA has not attempted, nor will it attempt, to build a single, K-12 curriculum. Its concern is with identifying the broad principles that can apply to any or all curriculum development efforts in science. It calls attention to the aspects or issues of science teaching and the most promising approaches in each area, and encourages the development of a coordinated curriculum, based on these, from kindergarten through grade 12 and beyond.

"The Association carries out these activities in regard to curriculum through its Curriculum Committee, through special conferences and through other activities."

The preceding paragraphs from Theory Into Action express the NSTA's basic philosophy as to its role vis à vis science curriculum.

In the project reported here, the Association, with the assistance of a grant from the U.S. Office of Education, has attempted to explore ways to further illuminate the overarching structure of science in a way helpful to curriculum planners and teachers. The effort is twofold: to inspire and enrich their view of science and to offer insight into the painstaking and yet challenging process of selecting and fitting together the experiences and learnings that eventually carry a student forward to an ever broader and deeper grasp of the big ideas of science.

The material included in this report is designed to aid elementary teachers, secondary school science teachers, curriculum coordinators, and administrators in the development of science curriculum materials. It includes rationale and guidelines for structuring the knowledge of the science disciplines into broad, pervasive conceptual schemes, which should be useful to those who are striving to produce interdisciplinary, integrated, or unified science curriculum materials. In addition, conceptual structures of the knowledge of biology, chemistry, earth science, and physics are included. These parts should be functional both to the developer of unified science materials and to those developing specific learning units in the various disciplines of science.

The Conceptual Schemes and Processes of Science delineated in Theory Into Action are restated and elaborated upon in the chapter entitled "Conceptual Schemes and Processes of Science." Chapters II and III point out some implications of the schemes for curriculum building and give some examples of ways in which they might be used. Chapters IV, V, VI, and VII present the conceptual structure of the knowledge of biology, chemistry, earth science, and physics, respectively.

Chapter VIII includes various patterns of organization of the knowledge of science.

Learning units, selected from contemporary science materials or prepared as illustrations, are analyzed, and the relationships of the concepts in the specific learning experience to those broad abstract concepts which comprise the Conceptual Schemes are cited.

The content, as well as its organization within this report, is based on the following assumptions:

1. Learning experiences should be related to the conceptual structure of the knowledge of science as well as to its processes.

2. The concepts and processes of science can be classified into hierarchical patterns.

3. The student should progress through the science curriculum at a pace consistent with his ability to integrate new knowledge into existing conceptual patterns.

4. Science concepts are intellectually more powerful than is unorganized information and hence provide the best basis for curriculum organization and learning.

5. The conceptual structure of science knowledge and the processes of science should form vertical threads of continuity through the curriculum from K-12.

6. Only a limited amount of basic science knowledge can be learned in grades K-12; therefore, only those concepts that are most likely to be of lasting value should be included in the curriculum.

7. The knowledge of each field of science can be organized into a hierarchy.

8. The various scientific disciplines all use a common set of major concepts around which all interpretations are developed.

9. The organization and sequence of learning experiences in a K-12 science curriculum are fundamental to effective learning.

10. The science curriculum should be a continuum of increasingly sophisticated concept abstraction and use of inquiry skills.

It is recognized that this document is not the final word in science curriculum development. Its limitations are many. But an attempt has been made to (1) present an understandable conceptual structure of science; (2) provide a functional conceptual structure of biology, chemistry, earth science, and physics; and (3) show how learning units can be developed through interrelating concepts from each of the science disciplines into a conceptual pattern of greater sophistication.

Finally, there is an attempt to show that the accumulated knowledge of science is the result of the intellectual activity of man, and therefore can be classified by man in numerous ways. The Conceptual Schemes is one way which we believe to be consistent with the nature of the scientific enterprise.

INTRODUCTION

Both scientists and science teachers are generally agreed that science has a dual nature, consisting of knowledge as well as process. These two phases of science are inseparable..Knowledge without process leaves a sterile set of facts with little or no value to the learner. The processes of science consist of what scientists do as they discover new knowledge and develop new ideas. Processes include developing hypotheses; designing experiments; gathering, collating, and interpreting data; drawing conclusions; and developing theories.

Processes are not unique to science; they may be found in other subject areas. It is possible to use the processes without using the knowledge of science. In this case, the processes are not science, but are a part of some other discipline. For these reasons, the National Science Teachers Association takes the position that processes and knowledge of science are inseparable, and both must be considered in science curriculum development.

The rapidly expanding fields of knowledge in science have made it impossible for any one person to learn all science knowledge. Any person who wishes to learn science must try to understand the broad concepts that provide the framework on which science is built, and use these concepts and general principles to interpret the many phenomena in the natural world about him. At the present stage of scientific development, and in the future, there appears to be no alternative to this approach.

For these reasons, the desirability of developing a statement of conceptual schemes of science is widely recognized. There may not be an equally wide recognition, however, of the fact that no single set of conceptual schemes can be proposed that will be satisfactory to all individuals concerned with developing a science curriculum.

Before a working statement of conceptual schemes can be proposed for curriculum planning, it is essential to identify the audience toward which the statement of schemes is directed. A set of conceptual schemes that would form a working basis for scientists who are considering problems of curriculum planning might be stated quite differently from one prepared for science teachers. It might also differ from one designed ~~for~~ general curriculum planners. It is improbable that one could prepare a single statement of schemes that would be acceptable to all three groups. The precise vocabulary of the scientist, which is so essential for expressing his ideas adequately, is meaningless to the average individual without a thorough scientific training. A statement of conceptual schemes that would be meaningful to the average classroom teacher would lack the precision and clarity of meaning demanded by the scientist. There is great likelihood--even probability--that a statment of conceptual scheme that would hold meaning for both groups would not be acceptable to either. It is a hard fact of reality that even the scientists themselves, representing the various disciplines, cannot all agree on a mutually acceptable wording of conceptual statements.

It is within this framework of inability to communicate effectively to all individuals with a single set of statements that the following set of conceptual scheme has been prepared. The statements and the expanded explanations are designed to communicate the meaning of science, as clearly as possible, to the curriculum planner, the classroom teacher, and the science teacher, even though it is necessary in some instances to forego some subteties of meaning and the precision of statement that would be desirable to the scientists. Faced with this realistic situation, the committee that has assisted NSTA in framing the following statements of conceptual schemes has made the decision that it is more important to communicate a set of conceptual schemes in a form useful to the individuals who must use them in planning courses of study and building a science curriculum. It is hoped that for those who are interested, the set can be expanded in content and precision.

The number of conceptual schemes to be developed presents another problem. The set of schemes presented is designed to bridge the gap, as well as possible, between the many published statements of scientific principles and concepts and a single all-encompassing conceptual scheme yet to be developed. The schemes are organized to include concepts developed by the systematic study of living and non-living objects.

The schemes can be stated in different ways. While the reasons for the decisions in selecting and phrasing the set of schemes that was finally developed may not be obvious to all readers, they may rest assured that the decisions were not made without lengthy debate and even some degree of dissatisfaction among some members of the group. However, it was agreed to proceed even though the perfect solution had not been discovered that reconciles all differences of opinion.

The remarkable thing is that although complete agreement was not reached, the extent of disagreement remaining is not as great as might have been expected. Differences have been mainly on the wording of the statements and the organization of ideas in an effort to produce greater clarity rather than disagreement on the significance of the idea that was being expressed by the statements. Probably one of the greatest frustrations experienced by some of the more scientifically oriented of the working groups was the lack of precision that is evident as a result of the desire to de-emphasize scientific terminology in preparing these statements.

PART I.

CONCEPTUAL SCHEMES AS A BASIS FOR CURRICULUM DEVELOPMENT IN SCIENCE

CHAPTER I

CONCEPTUAL SCHEMES AND PROCESSES OF SCIENCE

Science deals with the behavior of objects: from a single cell to a giant mammal, from tiny crystals to mountains, from cosmic dust to galaxies, from a one-celled organism to an ecological system. The aim of the scientist is the interpretation of the many aspects of behavior that are observed. The interpretation is based on conceptual schemes designed to provide a logical framework.

In a rough way all objects can be divided into two large groups of things: living things on the one hand and nonliving things on the other. Each object can be shown to be formed from one or more of the chemical elements. Presently we know of 104 such separate substances. In a general way each object is thought of as an example of matter (or stuff). Most aspects of the behavior of objects seem to involve the effects of objects on one another, and these effects are interpreted through the ideas of energy transfer and forces. Objects are also related to one another by assuming that they occupy a space of three dimensions and that in that space each object occupies a volume from which all other objects are excluded. This doesn't rule out the fact that even apparently solid objects may contain empty spaces into which other objects may fit. The behavior of each object can be described as a succession of events that forms its history and provides a basis for the idea of time.

These all-encompassing ideas of MATTER, ENERGY, SPACE, and TIME are so comprehensive in their application as to defy detailed description. A science student simply has to become used to them through repeated applications in many, indeed all, situations. However, there is a set of closely related concepts that it is useful to describe in more detail. This latter set of concepts is presented in the next section. Included in the set are particles, structure, interaction, change, random motion, probability, equilibrium.

A SET OF CONCEPTUAL SCHEMES

PARTICLES

Matter is thought to be composed of particles.

The major "building blocks" of matter are nuclei and electrons arranged in various combinations. Electrons are always the same whatever their source, but each chemical element has a characteristic nucleus. An electron is indivisible, but nuclei are complex and may be considered to be formed from neutrons and protons or from other more elementary sets of particles. These more elementary particles, however, are quite different from the three -- neutrons, protons, and electrons -- listed above. Two, the photon and neutrino, have zero rest mass, which means that they are observed only in motion, but when stopped are absorbed and disappear, contributing only mass and energy to the absorber. Others, such as the mesons and some of the baryons, are unstable with extremely short lifetimes (of the order of a microsecond or less) and change into more stable particles (electrons, protons, and neutrons). Finally, for every particle there appears to be an antiparticle (e.g., for an electron there is a positron which is its "mirror image" in the sense that certain of its properties are inverted and each annihilates its counterpart when the two collide, producing energy (photons). Particles and their antiparticles can coexist only for extremely short periods of time, and, therefore, are not found together in nature. The inverse process is also known; a photon may change to a particle-antiparticle pair.

More complex particles are also important. Gas behavior is interpreted in terms of molecules. Most living things are thought of as assemblies of cells. The maintenance of form and function through reproductive processes in living things is interpreted by genes, and the genes are considered to be complex molecules of DNA.

STRUCTURE

A sample of matter is generally a collection of particles arranged in a three-dimensional pattern.

Atoms, molecules, ions, crystals, cells, organisms, plants, animals, planets, and galaxies are best thought of as assemblies of particles. In each assembly the particles interact with one another. Hence the properties of an assembly are in part the sum of the properties of the separate particles, and in part properties that are characteristic of the assembly but not of any individual particle. Thus a human being has the property of self-awareness, but so far as we know this is not a property of a cell or a molecule or a nucleus. A collection of electrons exhibits behavior that is interpreted by the assumption of an exclusion principle, but this is not a behavior recognizable in a single electron. A metal crystal has such properties as conduction and ductility that are properties of the aggregate of electrons and nuclei but not of the individual particles.

Central to the interpretation of assemblies of particles is the idea that they are arranged in a three-dimensional pattern. This means that geometrical relationships are important. Whether one is classifying a plant by the way its leaves are arranged on a stem or interpreting the composition of a compound through the packing of electrons around nuclei, geometry furnishes a logical framework. Spheres, tetrahedra, octahedra, icosahedra, and many more complex forms turn up repeatedly. Notions of symmetry are among the most pervasive ideas.

The material units of the universe can be classified into sequences of structural categories, or levels of organization, such that several joined units of any one level form a single unit of the next level. For example, if protons, neutrons, and electrons are regarded as units of the level of fundamental particles, then certain combinations of these units form a single unit of a "higher" or more inclusive level, namely, an atom. Extended series of this kind represent hierarchies; this means, with very few exceptions, that a unit of any one level includes units of all lower levels as components and is itself a component within the units of all higher levels. Therefore, any given level contains fewer units than does any higher level; and each such unit may also be said to be more "complex" than any unit of a lower level. Thus, the hierarchy of levels describes a hierarchy of numbers of units and of complexities of units.

INTERACTION

The behavior of one object may be altered by the presence of other objects.

The interaction of ordinary objects is usually interpreted in terms of forces. The most important are referred to as gravitational, electrical, and nuclear forces. Both gravitational and electrical forces vary with separation distance by an inverse square law for objects that can be treated as points. For a moving object an electrical force also gives rise to a closely related magnetic force. It is presumed that there is a logical relation connecting electrical and gravitational forces,but efforts to establish the relation have yet to be successful. Nuclear transformations and properties are interpreted by means of a so-called nuclear force whose characteristics are still being worked out.

Chemical bonding in both living and nonliving materials involves electrostatic forces. The motions of planets and satellites are explained in terms of gravitational force. Other phenomena may also be explained in terms of these fundamental forces.

Though the behavior of all matter in the universe is probably determined by gravitational, electrical, and nuclear forces, some aspects of the behavior of more highly organized units of living matter have not yet been interpreted on these bases at this time. It is more fruitful to study the behavior of genetic material in terms of coded information and energy transformations required to utilize this information in cell processes. However, the information is coded largely, if not entirely, by the arrangement of electrons and nuclei into appropriate patterns.

CHANGE

The objects in a system may be arranged in such a way that the properties of the system undergo some change to give a new arrangement and a new set of properties.

The planets, natural satellites, stars, galaxies, and galactic systems are subject to transformations in substance, form, and position. These involve interactions which produce interchanges between matter and energy, exchanges of energy, and the systematic motion of celestial bodies in a gravitational field of universal dimensions. Movements of the earth and moon serve as convenient bases for time units such as day, week, month, and year.

Materials of the solid earth are constantly undergoing transformations from one form to another. The common rock types represent changes in the form and organization of the matter of which they are composed. In most instances, changes from one rock type to another also involve changes in volume, shape, and position of the material. The movement of molten rock material to the earth's surface and the transportation of sediment to the sea by rivers are familiar examples of changes in position. In contrast to the relatively slow geological changes, nuclear particles may undergo extremely rapid changes.

All life processes involve interactions whereby nonliving matter becomes involved in processes and forms characteristic of living matter and eventually returns to the nonliving state. These interactions inevitably require time and may require, or result in, changes in position.

Observations of galaxies, stars, planets, and our own earth suggest a sequence of changes over billions of years that has led to the present form of the earth in particular and the cosmos in general. The study of fossils and of living things suggests a sequence of changes that has led from the non-living to the living and increasingly complex forms of living things. These types of changes are referred to as evolutionary development. Evolution continues as a central process in the universe, on the earth, and in the organisms that inhabit the surface of the earth.

From studies of the rate at which changes take place comes the information that permits judgments as to the merits of alternative proposals regarding the mechanism by which particular changes might occur.

RANDOM MOTION

The particles making up matter are assumed to be in continuous, random motion.

The idea of particles moving at random is the essential feature of all changes. It provides a relatively simple model that is consistent with most of the properties of a gas. In the model of a gas the particles are called molecules. Gas pressure, temperature, diffusion, viscosity, heat capacity, heat flow, and many other properties are interpreted in terms of molecules moving randomly so as to collide with one another and with the particles comprising walls of the container. For a molecule that contains more than one nucleus there is not only translational motion but also rotation and vibration. The energy stored in the gas is distributed among these various types of motion. These collected ideas are referred to as kinetic molecular theory.

The phases of matter are also related to the motions of molecules on the basis of kinetic theory. The chief difference among the three states of matter lies in the strength of the attractive forces between particles. Attractive forces result in a negative potential energy. The potential energy is relatively low for solids and liquids and high (close to zero) for gases. Since temperature is proportional to the average translational kinetic energy of the molecules in a sample of gas, it follows that as energy is added to the sample, its molecular motion increases. Not all the energy goes into increasing the translational motion. The translational kinetic energy, however, largely determines the temperature of the sample.

The motion of particles, or units of matter, plays a major role in a wide range of phenomena. The entire field of current electricity (electrodynamics) is based upon the motion of charged particles. Diffusion phenomena in gases and liquids, and across permeable membranes, are accounted for in terms of kinetic theory; the motion of ions which plays so important a role in the biochemistry of living systems, involves both kinetic theory and electric field theory. Chemical kinetics, the study of the velocity and mechanism with which chemical reactions occur, depends upon the motions of molecules and ions. The oscillation of electric charges in a radio antenna gives rise to electromagnetic radiation. Differential heating and cooling of groups of molecules in the atmosphere give rise to winds, and other changes in molecular energy, kinetic and potential, account for most of the phenomena we class as weather. These are but a few examples of the various ways that the motion of units of matter is used to account for the organization and behavior of physical and biological systems and cosmic systems.

PROBABILITY

The behavior of matter is interpreted as the statistical consequences of the behavior of large numbers of particles.

Compared to ordinary experience with counting objects the number of particles is extremely large in even a small sample of matter. Thus a drop of water contains more than 10^{20} molecules (100,000,000,000,000,000,000). Such a number is vastly larger than the number of people on the earth, which is about 3×10^{9} (or 3,000,000,000). The arrangement and the behavior of molecules in a sample of matter therefore is best considered to be the average of the contributions by all the separate particles. When a small collection of particles is examined the motion, configuration, and many other properties vary over a range called a distribution.

Radioactivity is an example of a property of matter which follows the laws of probability and which can be described on a statistical basis. Atoms of elements such as uranium, thorium, and carbon^{14} spontaneously disintegrate by emission of particles. In any large group of such atoms it can be predicted that a certain number will disintegrate in some unit of time. However, it is not possible to predict when any given atom will disintegrate. So far it has not proved possible to relate the time of any one disintegration to any other observable property.

Another behavior of matter which can be predicted on a statistical basis is the transmission of characteristics from parents to offspring among living things. The laws of inheritance were first clearly established by Mendel. On the basis of the Mendelian laws, it is possible to predict the distribution of characteristics among a significant population of offspring. However, it is not possible to predict precisely the characteristics which will appear in a single offspring except in carefully selected special cases.

The main theories that develop the statistical interpretation are thermodynamics and statistical mechanics. Thermodynamics is that branch of science relating energy and changes in material. Statistical mechanics refers to the methods of statistically extending the deduced behavior of a small number of particles to describe or predict the average behavior of all particles in a system.

EQUILIBRIUM

All material systems tend to change toward an arrangement of minimum available energy with respect to the equilibrium state.

A system tends to change from its initial state toward a final state. The final state has properties that can be described as:

stable: does not change by itself

reversible: can be approached from at least two different initial states

sensitive: responds to disturbances from outside by changing to a new state but returns to final state when the disturbance is removed.

A final state with these properties is called an equilibrium state. The disturbances to which the system is sensitive determine whether the equilibrium is referred to as physical, chemical, gravitational, electrical, and so forth.

As examples, consider that heat flows from a warmer to a colder body without any necessary external changes, but the flow of heat from a colder to a warmer body takes place only when accompanied by appropriate external changes. Similarly a gas left to itself will expand but has never been observed to contract, or sugar and water placed together spread through one another but can be separated only with the accompaniment of external changes. There appears to be a general tendency for material to spread out or for energy to distribute itself more widely. All these observations support the second law of thermodynamics. In statistical terms every change occurs in a way that increases randomness. Living systems are characterized by their ability to collect and organize spread-out materials seemingly in violation of the second law of thermodynamics. However, a living organism functions only in an environment with which it exchanges energy and matter. As the living organism proceeds to organize itself, it simultaneously disorganizes its surroundings. These and all other observations are consistent with the proposition that all natural processes are unidirectional in character and tend to bring the universe ever nearer to a state of equilibrium, in which it will have lost its ability for further change.

A conceptual scheme owes its significance in science to its being the starting point for a logical development. It is this logical development that provides the connections among the observations in the laboratory and the field. The ability successfully to predict new phenomena is directly tied to an intimate awareness of the significant concepts.

There are other features of good science that are closely related to concepts. Unlike concepts these other features are not ordinarily directly involved in the logical development. Nonetheless they constitute essential preconditions for scientific activity. They might well be called

SCIENTIFIC CONVICTIONS

REPRODUCIBILITY

Science proceeds on the assumption that natural phenomena are reproducible -- the same conditions always lead to the same results.

PUBLIC KNOWLEDGE

Scientific knowledge is concerned with observations of objects that are accessible to public investigation -- this is in contrast to private inspection or internal judgments.

ACCUMULATIVE

Scientific knowledge is obtained in a piecemeal manner but new interpretations not only incorporate new information but also information obtained earlier.

UNLIMITED

Scientific investigations reveal an expanding universe of phenomena to be uncovered and interpreted -- new insights suggest new possibilities.

QUANTITATIVE

Scientific reasoning is based on logical analysis in which arithmetic and geometric relationships play a major part -- it is both quantitative and mathematical.

In scientific discussions much is made of the description of experiments and the explanation of results. It is not always clear what is meant by these two activities.

Owing to some still powerful traditions (positivism, pragmatism, operationalism) in the philosophy of science, the difference between description and explanation is often minimized, if not explicitly denied. But there is an inescapable difference between giving an account of observed facts; and an accounting for these facts, that is achieved by derivation from hypotheses or theories. Thus it is one thing to give an account (to describe), e.g., the phenomenon of the rainbow; and to explain it by deriving it from the optical laws of light-refraction, reflection, dispersion -- with physical geometry as an indispensable "partner" of such explanations. There are clearly descriptive endeavors, such as mapping the fixed stars in spherical astronomy; or in physical geography; or in the reconstruction of the stages of evolution in paleontology.

Single observed facts may thus be explained with the help of empirical (or experimental) laws; this may be styled "low-level explanation." And when an explanation is sought for the very regularities which are formulated in scientific laws, this can often be achieved by a theory; i.e., from the postulates of a theory, usually together with other suitable assumptions, the empirical laws can be derived logically (i.e., either deductively or probabilistically). This is "high level explanation."

In addition to postulates, scientific explanation often requires also the assumption of "existential hypotheses," e.g., such hypotheses as the assumption that atoms and their nuclei exist within matter (or in the assumption of field of force, such as the electromagnetic fields).

Scientific explanation is always relative -- in two ways:

(1) It depends on premises which at least in the given context are not themselves explained.

(2) The acceptability of the premises of explanation depends upon the degree of their evidential support, i.e., of their empirical confirmation.

The traditional view of scientific explanation according to which it must proceed from "self-evident" premises is now almost completely abandoned. It is now no longer required that scientific explanation "reduce the unfamiliar to the familiar." Most explanations in modern physics, chemistry, and biology proceed from highly unfamiliar (but well-confirmed) assumptions. (Cf. for example, the theory of relativity, quantum mechanics, the theories of molecular biology.)

The ultimate aim of scientific explanation is to "cover" a maximum of observable facts and regularities with a minimum of basic concepts and postulates. Progress along these lines has been remarkable ever since the time of Newton, but no one can foresee to what extent this program of scientific theory construction will be successful in the future. In any case, it seems plausible that chemistry is ultimately ("in principle") reducible to atomic and quantum physics, and that biological phenomena may ultimately be reduced to physics as well. Scientists in general are, in any case, sufficiently wary of "ad hoc" hypotheses, and they are fully aware of the futility (if not the meaninglessness) of absolutely untestable hypotheses. But they are willing to accept tentatively hypotheses that have only a very weak evidential support.

CONCLUSION

Science, the work by scientists and the study by students, is a human enterprise that seeks to explore the behavior of all those things that make up our world. The exploration consists of many different kinds of observations and the interpretation of these observations. Central to the interpretations are assumptions and the logical deductions from the assumptions. These assumptions and their logical consequences are referred to as conceptual schemes.

The various concepts are central to all science, and each can be illustrated by examples from the study of plants, animals, chemicals, rocks, soils, planets, stars, and any other objects. The key to the behavior of objects is careful observation of nature. The key to understanding objects is logical analysis of concepts.

CHAPTER II

CONCEPTUAL SCHEMES AS VIEWED BY THE CLASSROOM TEACHER

John H. Woodburn
Charles W. Woodward High School
Rockville, Maryland

Looming large in the mind of the classroom teacher is the compelling, relentless need to arrange approximately one hundred and fifty lessons each year for one or more groups of boys and girls. As for viewing a set of conceptual schemes, it is both a resource and a hindrance to have one's view influenced by the challenges inherent in planning, conducting, revising, and evaluating a full repertory of day-by-day lesson plans. However, the resources far outweigh the hindrances.

Sometimes the classroom teacher feels that he lives only from one day to the next. He knows, however, that if the experiences he provides are actually to influence behavior, all of them must add up to a relatively small number of "big ideas" being elaborated deep within the private domains of his students' minds. Expressed negatively, every teacher knows full well how easily his students forget promptly any day's lesson that fails to link effectively with a larger piece of something that is shaping up in the students' minds. Herein lies much of the reason the classroom teacher is so vitally concerned with the elaboration of a set of conceptual schemes which promises to embrace the pursuit of science, to guide our students in their efforts to capture its spirit and structure, and to link the successful pursuit of science with advancing the knowledge, comfort, and welfare of mankind.

We all inherit a rich treasury of scientific facts, laws, and principles. The literature of science also tells us something of the methods and procedures, mental and manual, whereby men and women have created this largess. It is relatively easy to deal out selected bits and pieces of this inheritance and identify same as one or another science course. It is a much greater challenge to order and arrange these bits and pieces in the way most likely to nurture in the minds of our students the experiences they must undergo in order to help them see how the fragments fit together. Here is where a set of conceptual schemes provides vital assistance. In planning science curricula, teachers and curriculum planners have a twofold goal in mind: to increase the variety of experiences with phenomena through observation and to increase the ability of students to interpret what they see.

Forward-looking school systems are trying to offer full science programs for their students at all grade levels. This could mean that boys and girls can look forward to as many as 1,800 science "exposures" or opportunities. At the same time that our evolving science program promises to give a student a large number of bits and pieces from which he can elaborate meaningful concepts, it also reveals how large must be the repertory of science teachers' lessons. A science class can consume an enormous amount of lesson material. Today's youngsters are conditioned against "re-runs." They want fresh material in each new day's lesson or to see old material, at best, presented in new settings.

Faced with the relentless demand to adopt, adapt, or create so many classroom and laboratory activities with which to furnish his science lessons, the classroom teacher is hard put to find time to order or sequence these activities in such a way as to nurture efficient concept elaboration in the minds of his students. But he must try, especially by joining forces with his supervisory colleagues who, being less occupied with tending the individual trees, can see the total forest.

To suggest how such efforts might proceed, consider the following illustrations. Let us begin with two major blocks of material. One block consists of a set of conceptual schemes as worked out by either intermural or intramural deliberations. The second block consists of the teachers' repertories of classroom and laboratory activities ordinarily associated with teaching a more or less typical science topic. For one example, consider three of the conceptual schemes as worded earlier in this document. "Matter is thought to be composed of particles." "The particles of matter are assumed to be in continuous, random motion." "All material systems tend to change toward an arrangement of minimum available energy with respect to the equilibrium state."

For the second block of material to use in this example, suppose that the following activities comprise a repertory of things which youngsters might confront whereby some of the interactions between matter on the one hand and light and heat on the other can be observed.

a. Observe the melting of a dozen or so ice cubes frozen from water dyed three different colors and arranged alternately on paper towels placed on a sunny window ledge.

b. Observe time required to thaw ice cubes wrapped in different colors of construction paper and placed on a sunny window ledge.

c. Fill two similar bottles with hot water. Pull a white sock over one and a similar black sock over the other. Use thermometer to compare cooling rates.

d. Compare cooling rates of hot water placed in black- versus white-painted bottles, both of which are placed in a large container filled with cold water.

e. Obtain two cans of slightly larger diameter than the bottles referred to in "d." Paint one white and the other black. Use a thin layer of candle wax to attach a coin to the outside of each can. Observe time required for coins to fall from the cans when first the black- and then the white-painted, hot-water-filled bottles are placed inside the cans.

f. As in "e" but with the cans painted on the inside rather than the outside.

g. Fit two bottles, one painted white and other black, with one-hole stoppers which are fitted with glass tubes bent at right angles. Place a bubble of water in each of the horizontal arms. Shine light on the total arrangement.

h. As in "g" except use a single length of glass tubing to form the right-angle bends and insert a single water bubble. Compare position of bubble when the system is in the dark versus under strong illumination.

i. As in "h" but use unpainted bottles filled with contrasting colors of water dyed with food colors.

j. As in "i" but compare effects when the system is illuminated with different colors of light.

k. Paint two bottles one white and the other black. Fill with water and insert one-hole stoppers fitted with 12-inch lengths of glass tubing. Place, say, five inches apart and put a burning candle between the bottles. Note water levels. If different in the two vertical tubes, find where candle must be placed to equalize water levels.

l. As in "k" but replace the burning candle with an ice column consisting of several large ice cubes frozen end to end.

m. Compare time required for a dish of snow to melt with and without charcoal sprinkled on the surface.

n. Compare time required for seeds to germinate in vermiculite in foam plastic cups, one painted white and the other black and both placed in a sunny window ledge in a reasonably cool room.

o. Compare times needed for a burning glass to char different colors of construction paper.

In metaphor, this set of activities which teachers can arrange for students represents what the workers in our profession can do. The three statements of conceptual schemes which preceded them represent what the thinkers in our profession feel needs to be accomplished. But it is not to be inferred either that this set of activities is, once and for all, the proper activities for confronting students with the phenomena they involve or that these wordings of conceptual schemes are the most discriminating statements of which the thinkers of our profession are capable. To entertain either point of view would simply divert us from seeking to exploit the promise inherent in what is about to be suggested.

In the language for which our profession is all too often twitted, we are trying to identify "where the student is" in order to improve the chances that an effective dialog can be initiated. And although this point will be developed in a future portion of this chapter, there is an urgent need to establish empathic conversation between the "workers" and the "thinkers" in our profession, especially the specialists in these two categories.

We can assume that, provided with even minimum instructional materials and permitted to teach in a reasonably wholesome physical environment, any teacher can solve the logistic problems involved in confronting his students with at least one of the activities whereby his students can observe some of the interactions between light and heat. But this leaves several questions unanswered. The most obvious one being which activity should be a unique experience for each grade level or which of these the students may have learned outside of school. The most esoteric question left unanswered asks for a precise description of how the student's confrontation with a specific activity becomes translated into a bit of the mental fabric from which his ultimate elaboration of a specific concept is to be woven.

These are difficult questions. Many men and women consider them unanswerable. Unfortunately so long as they remain unanswered, these questions lie dead athwart our path.

From at least one classroom teacher's point of view, a set of conceptual schemes promises to accomplish the exceedingly valuable function of structuring dialog between and among all of the levels of our profession. Conceptual schemes may well create the common language which will permit classroom teachers to bring to the conference table the kinds of things they know will work in our nation's classrooms. To this same conference table will come, hopefully, the men and women who have devoted their lives to capturing the spirit of science, its logical structure, and its vital role in the human drama. And on that day, far in the future, when the conference adjourns, the teachers will return to their classrooms with their repertories of activities pruned, amended, supplemented, and ordered in the sequence which holds promise of nurturing with maximum efficiency the elaboration of truly valid concepts in their students' minds.

Despite the pessimistic tone, progress is being made in establishing dialog among the various levels of the science teaching endeavor. There was a time when, in almost monolog fashion, each higher level bemoaned the lack of knowledge in their students--knowledge which, for sure, they would have had if their prior instruction had been effective. The lack of "adequate preparation," in turn, became an oft-cited reason why the instruction at each higher level could not be effective. And this kind of rationalizing is permitted so long as each level's responsibilities to its students are not yet clarified.

To allocate unique responsibilities to each level of our total educational structure, from kindergarten to postdoctoral, may be an impossible task. Again it may not be. Perhaps the existence of a set of clear-cut conceptual schemes can again serve as the common language for attacking this problem.

One aspect of such an attack will bring out the highly significant differences in the kinds of populations served at each level. Although it is assumed that the nation's total population is to be served through the elementary school level, we must admit that each higher level beyond elementary school serves an increasingly selected population. It seems that all citizens should gain at least a minimum understanding of all conceptual schemes. Maximum appreciation may be reserved for those people who stay in the educational channels longest. It follows that no single level of education can be expected to be responsible for all of a student's understanding of any single conceptual scheme. Each level should, however, graduate its students toward the next level with a maximum degree of anticipation toward gaining increasing appreciation of the conceptual schemes to which they have already been introduced.

Why this anticipation may be lacking is itself worth exploring. Very probably, student frustration stems more from the sophistication of the vocabulary than from the actual phenomena the student confronts as he advances through the total sequence of experiences designed to give him increasing appreciation of the conceptual schemes of science. Specialized terms introduced in advance of first-hand contact with the phenomena can be absorbed readily by only a segment of the total school population. Similarly, terms used to develop abstract postulates or theories in advance of confrontation with the phenomena these theories or postulates are intended to describe, put severe strains on the abilities of many students.

Unfortunately, the use of a specialized vocabulary retains a higher status as a symbol of scholarly achievement than does a feeling of comprehension and appreciation in the presence of nature's phenomena. If teachers can understand their proper role in arranging appropriate confrontations with phenomena for their students, perhaps they can avoid the frustrations which derive from attempting to use a vocabulary that not only remains meaningless to their students but also threatens to alienate students against approaching future instances of nature's phenomena with an open, unprejudiced attitude.

Thus, the conceptual schemes of science promise to provide the common denominator needed to bring about dialog between and among all levels of our educational system--dialog from which each level will understand better what must be done to improve the experiences our young people need in order for them to elaborate the learnings we hold to be essential for the citizenry of today and tomorrow.

Conceptual Schemes and the Integration of Learning

A set of conceptual schemes can help the classroom teacher build his instructional experiences into a more complete, harmonious, and coordinated entity. The process of integration applies not only within separate conceptual schemes. Some of nature's most significant phenomena invite the teacher to help his students see how several conceptual schemes become intricately enmeshed in the action of these phenomena. And with realization of the interlacing of conceptual schemes may come the realization of the wholeness of the universe.

Consider, for example, how many of the events and circumstances of the world around us are linked with the daily rising and setting of the sun. So long as the earth rotates and revolves around the sun, each spot on the earth undergoes almost continuous change in the amount of light, and hence heat, falling upon or radiating from it. Light being one of the ways in which energy is transferred thus keeps under constant stress nearly every plant and animal as well as the earth's rocks, waters, and atmosphere. And having evolved under these conditions of constant stress and strain, all systems, especially living systems, interact with environmental changes.

Among the conceptual schemes as worded in this document which are linked with the phenomena of the preceding paragraph are: "The behavior of one object is altered by the presence of other objects, and this interrelationship is called interaction." "The objects in a system may be arranged in such a way that the properties of the system undergo some change to give a new arrangement and a new set of properties." "All material systems tend to change toward an arrangement of minimum available energy with respect to the equilibrium state."

There follow several examples of the kinds of classroom and laboratory activities which teachers often arrange for their students. It is interesting to examine each of these activities from the perspective of identifying how each may give the student bits of insight into his world as science tends to describe and, thus, explain it. Furthermore, it is equally interesting to think about the kinds of comments the teacher might make or the leading questions he might ask whereby the student would be assisted in weaving these bits of insight into his own concepts and conceptual schemes.

a. Line several shoe boxes with plastic. Place a one-inch layer of moist vermiculite in each box. Plant six or so corn, bean, or other seeds uniformly spaced in each box. For one box, punch, say, four uniform holes across the center of the lid. For other boxes, place similar holes on a side, end, or other locations. Include some arrangements where several sets of holes are punched in the same box. Place all boxes under uniform lighting conditions.

b. As in "a" except use different sizes of holes. Design an experiment to determine whether there is a minimum size of hole that will permit responses by seedlings.

c. As in "a" and "b" except cover the holes with various colors of cellophane or other plastic. Arrange experiments to determine responses of plants where size of hole is in opposition to effectiveness of color of transmitted light.

d. Repeat "a," "b," and "c" using soybean, corn, tobacco, or other kinds of seeds known to carry the albino factor.

e. Grow variegated-leaf coleus plants, some in the dark and some in the light. Remove leaves from both sets of plants and place on blueprint paper. Cover with glass plates and expose to bright sunlight. Develop the blueprint paper and compare results.

f. As in "e" except use seedlings from seeds known to carry the albino factor. Grow the seedlings until at least the second or third true leaf appears.

g. As in "e" and "f" except prepare one set of leaves in which the chlorophyll has been removed. For this set, boil the leaves, first for a minute or so in water, then in alcohol, until they are as colorless as possible. After completing the blueprint process, transfer all leaves to iodine solution. Leave overnight and then repeat the blueprint process.

h. Grow two sets of seedlings, one in good garden soil and the other in vermiculite or other non-nutritive medium. Divide each set into two subsets. For each subset, grow one in the light and the other in the dark until either set of seedlings dies. Compare.

i. As in "h" except use seeds known to carry the albino factor.

j. Grow seedlings of bean, corn, or other species. As soon as reasonably large true leaves appear, line clear plastic envelopes (Baggies) with cobalt chloride paper. Secure these envelopes over selected leaves and close them as nearly airtight as possible. Observe after a few minutes.

k. As in "j" except use seeds known to carry the albino factor.

l. Fit test tubes with one-hole stoppers carrying glass tubing bent so that gases issuing from the test tubes may be led into limewater. Heat strongly in one test tube after another small quantities of sugar, starch (various kinds), paper, wood, and other substances which the students have reason to believe to be products of the photosynthesis process. Before heating, place small strips of cobalt chloride paper near the opening of each test tube.

These classroom and laboratory activities are representative examples of the kinds of experiences many science teachers arrange for their students. They represent the kinds of experiences science students have been exposed to for many generations of science teaching. The question is: As science teachers approach the final quarter of the twentieth century, how can they use these activities to nurture the elaboration of concepts in the minds of their students more efficiently than was accomplished by equally dedicated science teachers of earlier generations?

Obviously, this is the big, the crucial question--a question scarcely to be answered by sudden flashes of insight. It is more probable that answers will arise only after those of us who are engaged in pedagogy have elaborated and tested many promising hypotheses. One hypothesis claims that these kinds of classroom and laboratory activities will work more efficiently if efforts, overt as well as covert, are taken by the teacher to help his students integrate their experiences with these activities into some kind of complete, harmonious, coordinated entity. A set of conceptual schemes should aid the teacher in achieving the aims of these efforts.

Suppose, for example, that the teacher has been impressed by the implications to be derived from looking at living systems as being in equilibrium with environmental factors. Anything capable of bringing a living system under stress thus becomes capable of initiating an event in the natural world. Expressed in conceptual language, all events in the universe involve energy transfer and, conversely, whenever anything happens in the universe, one or another kind of energy transformation is taking place. Within this statement exists the means for any teacher to help his students integrate their experiences derived from confrontation with many, many activities of the type illustrated above.

Continuing this hypothesis, a teacher can encourage his students to think of a living system, be it a dormant seed or vigorous plant bursting into full flower, a hibernating woodchuck or the school's football hero, existing as it is at the moment as a kind of standoff between opposing environmental and internal influences. Expressed metaphorically, each living system at any one moment is a delicately poised teeter-totter either carefully balanced or undergoing changes whereby a dynamic state of balance can be re-established.

Assuming they are alive, the seeds a student pours from a seed packet are systems in a state of dynamic equilibrium. Although it is highly probable that submicroscopic changes are going on within the dormant seed, to all intents and purposes no visible changes are evident. Suppose now that the student brings the living system of the seed under stress by increasing the concentration of water in the seed's environment. Visible changes now become evident. The inference is that one or another equilibrium state has been upset. The germination of the seed and growth of the seedling are observable changes within the living system--changes which are likely to continue until a new state of dynamic equilibrium is restored.

Many readers recognize within the above illustration some of the spirit of the Le Châtelier Principle. Quoting a widely used chemistry textbook, this principle when expressed in the language of a generalization, says: "If an equilibrium system is subjected to a change, processes occur that tend to counteract partially the imposed change." How far we can go in extending this principle and using it as a pattern whereby students can examine phenomena, especially those occurring primarily in living systems, is debatable. Engaging in this debate, however, should not divert our attention from the spirit of what we are looking for, namely, instructional patterns which hold promise of helping our students integrate their classroom and laboratory experiences. Assuming that our working set of conceptual schemes reflects the best thinking we are capable of at this time, they certainly promise to the classroom teacher the kind of guidance he needs when he seeks his own ways to improve his day-by-day performance. It has been the intent of this section to show at least one classroom teacher's pursuit of said promise.

Conceptual Schemes As Goals of Instruction

Every lesson must be brought to some kind of close. There are many ways to close out a lesson. A teacher can terminate the analysis and description of a phenomenon in such a way as to suggest to his students that they have received the complete picture of the phenomenon. In contrast, a teacher can "adjourn" a lesson in such a way as to suggest to his students that the future holds increasingly accurate descriptions of the phenomenon under consideration.

Some teachers move from one to the next phenomenon with little or no attempt to have the students describe their experiences with the phenomenon. Other teachers emphasize verbaldescriptions of their experiences and go to considerable effort to provide their students with the specialized vocabulary whereby their experiences can be communicated effectively.

Some teachers are willing to close out a lesson by simply labeling or naming a phenomenon. Other teachers dwell at length on the interactions of all elements involved not only within the phenomenon but also between it and related phenomena. Some of these teachers include or even place special emphasis on how this phenomenon becomes involved in the knowledge, comfort, and welfare of mankind.

Very probably, the worst lesson-closing leaves the student feeling that he knows all there is to know about the phenomenon around which the lesson evolved. Equally unsatisfactory would be the condition in which the student feels that simply learning a term that is used to identify a phenomenon completes his understanding and appreciation of the phenomenon. Adoption of a set of conceptual schemes should serve to avoid both of these kinds of lesson-closings. Even though they remain pretty much the concern of the teacher and are seldom communicated as such to students, conceptual schemes alert the teacher constantly to the large ideas to which each day's lesson contributes.

It is amazing how readily many students jump to the conclusion that they have grasped the total significance of the bits and pieces of science which comprise their daily lessons. This is evidenced in several ways. At a very narrow level, sometimes students cannot recall information that was taught in previous lessons unless the teacher words his questions in very much the same way that the earlier lessons were brought to close. Information taught in previous years may have slipped away, but the looks on students' faces change abruptly when the current year's teacher uses the same terminology or "catch phrases" that were emphasized by previous teachers.

Unexpected results from a classroom or laboratory activity can also bring out in operational fashion how thoroughly students grasp the true nature of a phenomenon. Consider the following examples.

a. A potato was cut into four uniform portions. One portion was placed in moist vermiculite and left in the dark. Another portion in moist vermiculite was placed in the light. The remaining two portions were placed in dry vermiculite with one portion left in the light and the other in the dark. All four were placed in plastic bags that were closed by tying a knot in the open end. Several months later small new potatoes appeared in several of the plastic bags and only the empty, shrivelled skin of the original section of potato remained.

b. Two-foot lengths of the terminal portion of weeping willow twigs were cut into thirds. All three portions were placed in water in test tubes with the center portion put upside down. After several weeks rootlets appeared near the bottom portions of all of the twigs which were placed right side up. In about half of the cases observed, rootlets also appeared near the bottom portions of the upside down twigs.

c. Bryophyllum leaves were placed in plastic bags, some containing dry and others moist vermiculite. In general, more small plants appeared in the notched margins of the leaves left in dry vermiculite than in the moist vermiculite. However, the plantlets appearing on the leaves left in the moist vermiculite were more vigorous.

Students for whom the mysteries and miracles of photosynthesis had been eulogized were totally amazed to discover the new generation of potatoes which had been produced in the absence not only of light but also the usually essential chlorophyll. Other students were equally amazed at the instructor's surprise with the looks on their faces as much as asking: Isn't this the way potatoes always grow? In either case, the instructor was forced to discuss the total activity and its results in analytical fashion rather than to dictate any kind of closed-end conclusion. Having at hand a set of conceptual schemes which encompasses a maximum number of nature's phenomena assisted immeasurably in the analysis of these unexpected results.

The willow twig activity provided a second instance in which the instructor shared in his students' confusion when confronted with results from a seemingly straightforward activity. In this case, the activity moved into a second phase with each student invited to arrange whatever investigation of the phenomenon he believed might help pin down the variables involved in the total activity. With only minimum prompting by the instructor, experiments were designed in which the probable effects of various environmental factors were investigated. After considering all of the results from these experiments, the students were left with the hypothesis that the formation of roots on the twigs which were right side up may diffuse into the surrounding water an auxin which permitted subsequent root development on the upside down twig.

The interpretation of the total willow twig activity provides a good illustration of how conceptual schemes can provide a frame of reference which not only helps the teacher work toward the achievement of ultimate goals but also provides guidance en route. Recall, especially, the conceptual scheme stated earlier in this document as, "The behavior of one object is altered by the presence of other objects, and this interrelationship is called interaction."

There is greater difficulty in interpreting the results from the Bryophyllum leaf exercise. Perhaps a part of the reason lies in not having faith in the results inasmuch as only a few leaves were involved in the original exercise. Perhaps this exercise points to a gap in the array of conceptual schemes developed in this document. An adequate interpretation cannot be found readily in such statements as: "Living systems are characterized by their ability to collect and organize spread-out materials seemingly in violation of the second law of thermodynamics. However a living organism functions only in an environment with which it exchanges energy and matter. As the living organism proceeds to organize itself, it simultaneously disorganizes its surroundings."

A set of conceptual schemes, in general, helps the teacher guide his students through the interpretation of unexpected results from classroom exercises and laboratory activities. In the absence of direct assistance in revealing an adequate interpretation, the teacher is encouraged to allow the students to retain their observations of the apparent discrepant event in anticipation of future interpretation. The teacher realizes that his role in guiding his students toward the ultimate elaboration of concepts takes precedence over being apparent master of all immediate events and circumstances.

Conceptual Schemes and Convictions Concerning the Methods and Procedures of Science

From the classroom teacher's point of view it is difficult to divorce the methods and procedures of science from the usual treatment of the so-called content of science. The phenomena of nature and man's efforts to describe them accurately are all of one piece. To attempt to transmit to our students man's descriptions of phenomena without including efforts to have our students appreciate how these descriptions were achieved is to give them only half a loaf. To attempt to develop in our students not only appreciation of but also proficiency in the methods of science, mental and manual, is particularly hazardous if we substitute anything for actual confrontation with the phenomena of nature.

Teachers are painfully aware of the problems encountered when students are expected to transfer their training from one domain and to apply it to even closely related domains. It can be done. And there are situations in which the teacher has no other choice. In the teaching of science, however, these situations arise only seldom. Usually, by nature of the methods the teacher uses in his classroom or laboratory, the students concurrently gain experience in the methods and procedures, tactics and strategies of science, as the students are being confronted with phenomena.

It is especially hazardous to attempt to build lessons intended to teach the nature and methodology of science around artifact phenomena. In the first place, we can never be sure that we have interpreted faithfully any or all of the things men and women do during their pursuit of science. Nor can we be sure that any artifact situation truly parallels a naturally occurring event or circumstance. And then we have the added task of helping our students transfer what they have learned and then to apply it to their behavior in the real world of science.

For the sake of efficiency, it is effective at times to focus student attention on single aspects of the ways scientists attack their problems. The teacher can, for example, pay special attention to the events and circumstances which seem to accompany a scientist's finding himself with a problem. And significant portions of lessons can be devoted to his struggles to shape up an efficient statement of his problem. But both of these goals are best approached in the actual presence of phenomena.

Similarly, lessons can be devoted to appreciating how scientists elaborate their hypotheses, how hypotheses so often are woven from the warp of first-hand observations and the woof of background knowledge. Valuable lessons stem from detailed analyses of hypotheses which turned out to be diversionary as well as those which kept the scientists moving more directly toward an accurate description of a phenomenon. Again these lessons are set in the presence of selected phenomena.

To teach students to design, conduct, and interpret the evidence from experiments is a vital adjunct of instruction in science. But where can better instructional material be found than in the designs, conduct, and interpretation of experiments to prove actual hypotheses? Well-educated students must know the final outcome of the most significant experiments which have been conducted during the pursuit of science. What better way is there to teach the end products of episodes in science than to share with our students the total episodes?

Finally, many of us want our students to appreciate the function of science in our total society and culture. We want them to understand the differences between beliefs based on superstitious or managed explanations of phenomena and those which follow from ever-increasingly accurate descriptions of these phenomena. We want students to appreciate what science vigorously pursued can mean to the comfort, health, and welfare of a citizenry. To divorce these understandings and appreciations from the actual pursuit of science, however, and to substitute preachment or exhortation puts us in competition with hucksters of all kinds of interests and points of view--interests and points of view today's boys and girls are becoming increasingly inclined to take with increasingly large pinches of salt.

Yes, the verb aspects of science are important. So are the noun connotations. But both are needed to make sentences and sense.

CHAPTER III

USING CONCEPTUAL SCHEMES IN CURRICULUM DEVELOPMENT

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Introduction

As the preceding author has so eloquently stated: Youngsters may be investing 1800 hours in science classes. Teachers are faced with preparing and presenting some 150 hours of "live programs" per year. Curriculum planners are faced with mapping out the broad outlines of a consistent and smooth-flowing program for varying segments of time from a single year to an entire K-12 program. Parents and the public expect some degree of uniformity between school systems and--as a final result--young people able to cope with problems involving science, able and interested also in continuing to extend and deepen their concepts in science and to use them in real-life situations.

It is impossible to teach "all about" science. The only alternative to an "armchair" approach to curriculum development--that is, arbitrarily deciding what content is to be taught--is to base the selection of curriculum content on the extent to which the topics contribute to an understanding of a few conceptual schemes of science. The purpose of this chapter, then, is to suggest how this may be done and give a few examples of curriculum materials that have been developed by using this process.

Science education cannot survive on the basis that "It doesn't matter _what_ you teach, it's _how_ students learn that counts." Both the subject matter content and the learning process are essential aspects of an educational program. It must not be forgotten that the presentation of the conceptual schemes in this document provides relatively few suggestions concerning the learning process. This does not mean, however, that the learning process is not an important aspect of the curriculum. Rather, the statement of a set of conceptual schemes to be used for the development of a course of study provides just one aspect of the learning situation. The thesis of this project is that a group of overarching conceptual schemes --and a proposed set has been presented in the preceding chapters--provides a framework for the efforts of students, teachers, curriculum planners, and the public.

Selecting and Organizing Content

There are at least two possible approaches to the use of conceptual schemes for the selection and organization of content for a science curriculum. The more obvious of these processes is to select a scheme and bring together content materials, student activities, and other resources that will contribute to the understanding of the scheme that has been selected. Examples of such efforts by several groups and individuals will be given later in this chapter.

This approach has several drawbacks. One of these is the inherent danger of assuming that the student's ability to verbalize a statement about a conceptual scheme is an indication that he understands it. Students have developed a great facility in playing around with words that have little, if any real meaning to them. Adults, even science teachers, are sometimes guilty of using terms that they do not understand; it is no reflection on students that they often do the same thing.

An even greater weakness of this approach is that no major conceptual scheme can stand by itself. All major conceptual schemes of science are so interrelated that any one of them might provide the starting point for the development of an entire science curriculum. Treating each scheme separately may give the student the impression that this interrelationship does not exist. Also, there is a probability that there may be overlapping of content as the various schemes are studied, because the same topic will need to be treated in the context of several schemes.

The alternative approach to the expansion of each conceptual scheme on an individual basis is the more traditional practice of developing a curriculum by assembling a series of topics that will make up a sequential science program and emphasizing the various conceptual schemes as they fit into the content that has been selected. This process is more easily understood by teachers, because they are more accustomed to thinking in these terms.

This approach also has its drawbacks. Because the teacher is more familiar with this type of curriculum organization, there is a danger that the teacher may be inclined to use traditional teaching techniques. This may lead the teacher to emphasize memorization of facts, and thus detract from the desired emphasis on the conceptual schemes which underlie the content being taught. Another danger is that the teacher may fail to see the interrelationships of the underlying schemes and thus may neglect to alert the pupils to these relationships.

The first approach helps the curriculum builder to keep the ultimate goal in sight. The second approach makes its greatest contribution as a guide for selecting materials and integrating the curriculum. It has the added advantage that the teacher is often more accustomed in dealing with curriculum materials organized on this pattern.

Organizing for Action

With these conditions in mind, how might a curriculum committee begin to develop an instructional program? It would seem obvious that the first step that a working group should take in developing an instructional program based on conceptual schemes would be to familiarize themselves with the intent and content of a statement of schemes. It might be advisable to invite a well-oriented scientist to discuss the concepts expressed in the schemes with the committee, until everyone has an acceptable idea of what the schemes are all about.

The next logical step would be to study the existing curriculum, to identify the desirable parts that should be retained in the planned revision and to devise ways of bridging the gap between the existing curriculum and the one that is being planned. It should be remembered that the most successful curriculum projects are developed through a process of evolution, rather than by an act of creation. There are many paths by which curriculum revision may successfully be achieved, and it is the responsibility of the curriculum committee to select the path that appears to be the most satisfactory, so that it will merit the support of the remainder of the community.

Just as the curriculum cannot be created in a vacuum, it will not achieve success unless it has the support of the administration, the teachers, and the community. One of the initial steps in developing a new approach to curriculum improvement is to enlist the support of the individuals whose backing must be obtained in order to make the project a success. Too often failure can be attributed to a lack of public relations and community support, rather that to the inadequacy of the project.

From the study of the existing curriculum, the community and faculty philosophy, and the goals that have been set, a working plan may be developed. By studying existing examples of the ways in which other groups have approached curriculum development, a decision might be made of the alternative path to approach the problem. These were mentioned in the previous section. Once this information has been obtained and the necessary decisions agreed upon, the committee should be ready to proceed to the more specific problems of curriculum development.

Along with already available materials, the committee should consider fresh, innovative experiences that may be drawn from the imagination and talents of teachers, students, scientists, and curriculum planners. Among these, special attention is directed toward the potentials of special environments--ranging from a small windowsill area, through outdoor school camps, to oceanography research vessels for secondary school classes. It is in these environments that some of the conceptual schemes can best be taught. Ideas of the interaction between living and nonliving things, among ecological groups, and the ever-present change which is one of the most universal characteristics of matter, can be observed at every turn of the trail and in every wave of the ocean.

Conceptual schemes may form formal, or perhaps informal, criteria underlying all the planning and teaching and, hopefully, all of the student's learning. Without some method of emphasizing principles and relationships, such as a set of conceptual schemes, to provide the basis for organizing and interpreting scientific phenomena, the study of science may become an unorganized and purposeless activity for the student. Enough is known about the half-life of memorized facts and information to show evidence of the futility of teaching information that does not have a unifying framework. Such a course of study becomes a purposeless academic exercise in the life of the individual.

Course planning should aim to bring to the students the practical aspects of science as well as the theoretical, for technology as well as science is an important facet in their lives. Although the student can benefit from knowing how the basic principles of science operate in his everyday life, his contact with technology and its impact upon him as an individual and on society as a whole are far more frequent that is his contact with "pure" science.

Examples of the Conceptual Schemes Approach

The National Science Teachers Association has been pleased to see the extent to which the idea of using a set of conceptual schemes has provided the basis for curriculum development.

For example, the authors of one series of science textbooks express the "Interaction" conceptual scheme in such language as: "Living things are interdependent with one another and with their environment. A living thing is the product of its heredity and environment." * Each of the teacher editions of each grade level displays a chart showing how the students' progress toward elaborating each conceptual scheme may unfold as they move through the separate grade levels.

Continuing this example, the work of the first-grade teacher should be directed toward having students realize that living things are affected by their environment and that living things reproduce. At the second level, special attention should be given to the dependence of living things on their environment for the conditions of life and the similarities in the reproduction of related species. At the third level, teachers are expected to feature how each environment is "outfitted" with its characteristic life forms and that we tend to relate different species on the basis of possession of common structures. At the fourth level, emphasis is placed on the exchange of matter by living things with their environments and the limitation of a species to a unique environment. At the fifth level, photosynthesis and the cell theory receive major attention. In the final year of the elementary school, emphasis is placed on how living things are adapted by structure and function to their environment and that the characteristics of a living thing are laid down in a genetic code.

By providing this grade-level breakdown of conceptual schemes, the publisher of this textbook series enables its users to identify almost at a glance how its authors hope to assist the teacher in the development of a clear-cut set of conceptual schemes in the minds of his students. In fact, throughout the teacher editions detailed suggestions appear under such headings as: Introducing the Lesson. Developing the Concept. Extending the Concept. Additional supporting documents provided by the publisher show how each of the subconcepts at each grade level can be broken down into "understandings." Observations and investigations are listed whereby these understandings may be nurtured.

It is interesting to examine the strengths and weaknesses of this kind of effort to incorporate conceptual schemes within the central structure of science courses and the total school science program. To improve perspective, however, this will be delayed until additional examples of similar efforts have been considered. By examining an array of such efforts, perhaps criteria will develop whereby we can predict the "goodness" of proposed attempts to use conceptual schemes to establish the relationships which exist between and among the bits and pieces of individual courses which make up total science programs.

The authors of another effort** emphasize that a conceptual scheme is not taught through a specific verbal presentation. They caution against the hazards which arise from students learning to verbalize statements that they cannot understand. (Recall that in the above textbook example, the wordings of the conceptual schemes and their accompanying subconcepts appear only in the teacher editions, not in the student editions.)

* Concepts in Science (Textbook series) Harcourt, Brace & World, New York. 1966.

** "The Relative Effectiveness of Two Methods of Instruction in Teaching the Classificational Concepts of Physical and Chemical Change to Elementary School Children." Technical Report No. 39. Center for Cognitive Learning, Madison, Wisconsin. 1968.

These authors also emphasize how concept development must begin in the primary grades and then develop gradually throughout the entire educational life of an individual. The complexities of a conceptual scheme begin with simple elements and then expand as the student continues to learn.

To illustrate their approach, these authors select the Interaction conceptual scheme. Beginning in the lower grades, the principal goal is to build in the minds of the students a general concept of force and the identification of gravity, magnetism, and electricity as being forces. In the middle grades, the broad topics to be emphasized include: Newton's Laws of Motion, the Laws of Reflection, the Laws of Magnetism, the Field Concept, the Structure of Matter, Atomic Forces, Nuclear Forces, and Vectors. The upper grades are broken down into the traditional specialized science courses. In biology, contributions toward student elaboration of the Interaction conceptual scheme are achieved primarily through the topics of reproduction and genetics, metabolism, and sensation. The topics especially cited for chemistry include chemical bonds, chemical reactions, and ionization. For physics, the topics are electromagnetism, light and radiation, electricity and magnetism, and falling bodies. For the earth and space sciences, the topics especially cited include solar energy, solar wind, Van Allen radiation belts, the earth's magnetic field, orbits and satellites, and extremely high pressures.

For a third example of efforts to incorporate conceptual schemes in curriculum building, the author* states a conceptual scheme that seems to blend several aspects of several of the conceptual schemes as worded earlier in this document.

Another example of the use of a conceptual scheme in curriculum development is provided by the material that was developed by a team from the University of Wisconsin** that dealt with the scheme: PARTICLES: Matter is thought to be composed of particles.

In this case, the authors' primary concern was to investigate in pupils in grades 2 to 5 the relative levels of understanding of certain concepts related to the conceptual scheme. The design of the investigation required the instruction procedures employed for each concept and the sequence and rate of progress from concept to concept be uniform for all groups and grades of students taking part in the investigation. This requirement led to the creation of a very tightly structured document, a small part of which is reproduced on the following pages.

* Developed by James A. Rutledge, University of Nebraska, for the project reported here.

** Carey, Russell L. "Relationship Between Levels of Maturity and Levels of Understanding of Selected Concepts of the Particle Nature of Matter." Technical Report No. 36. Center for Cognitive Learning, Madison, Wisconsin. 1968.

UNIT II: CONCEPTS 4-11

Concept 4: Some matter is composed of molecules.

Teacher Does	Teacher Says
A. Visuals and models for Concept 4. 1. Show poster with Concept 4.	A. All matter is believed to be made up of particles, but not all matter is composed of the same kind of particles. Some matter is made up of particles called molecules. So we say, some matter is composed of molecules. Water, sugar, oxygen, and many other things are made up of particles called molecules.
2. Write the words "not continuous" on the blackboard.	Remember, matter made up of particles is not continuous. Water, sugar, and oxygen are not continuous. If they were continuous they would not be made up of particles.
3. Show a model of a water molecule.	This is a model of a water molecule. A small amount of water would be made up of a large number of water molecules. This is because water molecules are very small.
B. Show the students a model of a water molecule and a model of an oxygen molecule.	The results of experiments have shown there are many different kinds of molecules. A water molecule is different from an oxygen molecule. Both the water molecule and an oxygen molecule would be different from a sugar molecule.

Concept 5: Molecules are composed of atoms.

A. Electrolysis of water demonstration.	A. This apparatus is used to take water apart. The water will be decomposed.
1. Show the electrolysis of water using a Hoffman electrolysis apparatus.	By decompose, I mean to separate the water molecules into the parts which make up the water molecules.
2. Write the word "decompose" on the blackboard.	Water is in the apparatus. The apparatus is turned on. What do you notice is happening within the apparatus? One tube of the apparatus has more gas in it than the other tube.

			Which tube has the most gas in it? Tube 2 has twice as much gas in it as Tube 1.
B.	Test for a certain gas in Tube 1. 1. Fill test tube with oxygen. 2. Put a glowing splint into the test tube containing oxygen. 3. Write the word "oxygen" on the blackboard.	B.	Let us test for a certain gas in Tube 1. What did I do? What happened? If a glowing splint is put into a container of pure oxygen, the splint will burst into flame immediately. Did the glowing splint burst into flame? Then did Tube 1 contain oxygen?
C.	Test for a certain gas in Tube 2. 1. Fill test tube with hydrogen gas from apparatus. 2. Put a burning splint into the test tube containing hydrogen. 3. Write the word "hydrogen" on the blackboard.	C.	I will test for a certain gas in Tube 2. What did I do? What happened? This is a test tube containing hydrogen gas. I will insert a burning splint into this test tube of hydrogen gas. What happened? Did the same thing happen with the test tube of hydrogen as with the test tube filled with the gas in Tube 1? Then did Tube 2 contain hydrogen?
D.	Explanation of oxygen and hydrogen source.	D.	Where did the oxygen and hydrogen come from? A water molecule is made up of one part oxygen and two parts hydrogen. The one part of oxygen is called an atom of oxygen. The two parts of hydrogen are called atoms of hydrogen. Atoms are also believed to be particles.
	1. Show a model of a water molecule which can be taken apart. 2. Take the model apart.		This is a model of a water molecule. The water molecule can be decomposed into one atom of oxygen and two atoms of hydrogen. So a molecule of water is composed of two atoms of hydrogen and one atom of oxygen. This helps us to explain that water decomposes into two parts hydrogen and one part oxygen. Remember there was twice as much hydrogen in Tube 2 as oxygen in Tube 1.
E.	Show poster with Concept 5.	E.	Not only is a water molecule composed of atoms, but all molecules are composed of atoms. Some molecules are composed of only one atom. Other molecules are composed of more than one atom. It is accepted that there are many kinds of atoms.

Such on-going efforts suggest that it is possible to use conceptual schemes to link together the separate activities which add up to science courses and total science programs. Such efforts, however, differ markedly. Some of the differences are initiated in the rewording of the conceptual schemes, placing increased emphasis on some, de-emphasizing or even omitting others, or attempting to use language that the "man in the street" might understand, versus the specialized vocabulary of the content, logic, and philosophy of science.

Examples of the Topical Approach

If an on-going program has been well structured, it is possible to rework the structure and derive the advantages that may be obtained from incorporating the conceptual scheme point of view, without sacrificing the original structuring. To restructure the curriculum under these circumstances, however, can be only as successful as the concurrent points of view are compatible. An example of how a single topic can be used to introduce several conceptual schemes is shown by the example below, taken from the Baltimore County Junior High School Science Program.

Grade Seven
Structure of Matter

Teachers Guidesheet

What Methods Can You Use for Separating the Materials in a Mixture?

Goals

1. Identifying various methods for separating mixtures
2. Applying the methods learned to a new situation

Materials

- test tube rack
- 2 test tubes
- watch glass or other shallow container
- graduated cylinder
- wood splint
- toothpick
- hand lens or tripod magnifiers
- salt
- iron filings, 60 mesh or smaller
- magnet

Directions

1. The term measure is an arbitrary unit selected to represent the amount of substance that can be held on a ¼ inch of a wood splint. Explain this to the students before they begin to work.
2. The time required for evaporation of the liquid in Step 8 can be shortened if a stream of air moves across the watch glass.

What Methods Can You Use for Separating the Materials in a Mixture?

Materials

test tube rack
watch glass
wood splint
hand lens
iron filings

2 test tubes
graduated cylinder
toothpick
salt
magnet

Directions

SCHEMES TO BE TAUGHT:

PARTICLES

1. Mix one measure of iron filings with four measures of salt thoroughly in a watch glass. Can you still distinguish the iron filings from the salt by using the hand lens?

PARTICLES, INTERACTION

2. Try to separate some iron filings from the mixture by using the hand lens and a toothpick. Is it possible to separate the salt and iron filings by this method?

INTERACTION

3. Move a magnet closely over the remaining mixture. How do the iron filings react?

4. Is it possible to separate the salt and the iron filings by this method?

PARTICLES, INTERACTION

5. Mix thoroughly in a test tube one measure of iron filings with four measures of salt. Add 10 ml of water to the test tube. Close the top with the thumb and shake the test tube vigorously for a few minutes. Allow the test tube to stand for one minute. What happens to the salt?

6. What happens to the iron filings?

7. Is it possible to separate the salt and the iron filings by this method?

8. Pour off the liquid into a clean test tube. Pour a few drops of this liquid into a clean watch glass, and allow it to evaporate. Describe what happens.

____

____

Interpretation

1. Describe several methods for separating the substance in a mixture.

____

____

2. Was the iron or the salt changed into a different substance at any time during the experiment?

____

Explain. ______________________________

3. What methods would you use for separating a mixture of sugar, sand, and iron?

____

____

Related Investigations

INTERACTION

1. Can a mixture be separated by gravity? Get a sample of soil containing a mixture of various sized particles. Pour enough of this soil into a one-half gallon milk bottle to half fill the bottle. Fill the remainder of the bottle with water. Place a cap on the bottle and shake vigorously for a few minutes. Set the bottle aside and leave it undisturbed for two days. After two days, observe the contents through the side of the bottle. Describe what you observe. Give a reason for what you observe.

2. From a reference book find out how a centrifuge works. List some of its uses.

SCHEMES TO BE EMPHASIZED THROUGHOUT THE EXPERIMENT:

REPRODUCIBILITY
ACCUMULATIVE

Another example of the way in which conceptual schemes might be woven into a curriculum topic may be seen by examining a part of a unit on Ecology, which was prepared for seventh-grade students in the Alfred I. DuPont School in Wilmington, Delaware:

B. Levels of organization

1. Physical environment--study of characteristics of life and subdivisions within each environment.
    - a. Terrestrial
    - b. Marine
    - c. Fresh water
    - d. Local biomes
2. Levels of living organization
    - a. Forces determining
        - (1) Procurement of food--food chain
        - (2) Interaction--Producers consumers
            - (a) Positive
            - (b) Negative
        - (3) Stimuli-response
          Limiting factors:
            - Food availability
            - Physical factors
            - Space
            - Competition
            - Hormones
        - (4) Camouflage--physical adaptions

(The transfer of food and energy from one organism to another is a food chain, and interlocking food chains form a food web)

(Securing food is a prime activity within any biotic community)

(A delicate balance exists in nature between producers and consumers--predator and prey. This balance is easily upset by man if he does not have a thorough understanding of its workings.)

(All organisms respond to stimuli in their environment)

(From Living Science in A Physical World, Alfred I. DuPont School, 1965)

In this single part of the unit, it would be possible to emphasize six of the schemes mentioned in Chapter I: structure, interaction, probability, equilibrium, accumulative, and quantitative. It would seem that introducing several of the conceptual schemes into a portion of the curriculum, as has been done in the example, as the content lends itself to dealing with them, may be a better approach than trying to emphasize just one of the schemes, at the expense of the others that might remain obscured.

A portion of the Minnesota Department of Education publication, Experiences in Science (1962), also illustrates that a single portion of the curriculum is adapted to teaching the interrelationships of several schemes (see next page):

Space

The vastness of the universe and some theories of origin	
Ancient cosmology based upon preconceived philosophical and theological notions; the finite universe	Ancient Egyptian Babylonian Chinese Greek Roman
Modern cosmology based upon some evidence provided by observations and instrumentation; the infinite universe	Medieval Modern Evolutionary--expanding universe Steady state--density and shape constant
Much of the structure and content of the universe are labeled or known	Nebulae Galaxies Composition Shape Star clouds and dust
The size of the universe	Methods of measurement: Doppler shift Relative brightness Relationship of time and distance The light year
Galaxies: an example, The Milky Way	Composition Made up of many stars Structure General shape: rotating "whirlpool" or "pinwheel" Attachments Motion Of stars within the galaxy Of galaxy within the universe Size of distribution Not uniform
Some forces shaping our universe	Gravitational forces Centrifugal forces Newton's Laws
The origin and life cycle of the stars	Original ideas - historical Present concepts Energy dissipation of the stars

In fact, every one of the conceptual schemes listed in Chapter I can be illustrated while teaching the portion of the topic shown above. Indeed, it would be very difficult to teach this section of the curriculum without emphasizing more than a single conceptual scheme.

A portion of the publication, Science Education for Oregon Schools (1965), provides a more detailed account of student reaction while experimenting with a topic--in this instance, drops of water. The publication is organized by using a topical approach in teaching the NSTA set of conceptual schemes. The material is not graded, and in a portion of the introduction it is stated that any of the topics may be used at different grade levels by varying the sophistication with which the topic is studied. A portion of the publication is quoted here.

DROPS OF WATER

As an exercise in observation, the teacher asked the class one day if any of them had ever carefully observed a water drop. (The preceding module had run its course, there had been an intervening vacation, and they were somewhat at loose ends insofar as the study of science was concerned.)

- In this module only a skeleton of the activities is presented; the ideas can "snowball" if given a chance.

The idea that a drop of water could hold any secrets was considered to be about as absurd as an idea can be--but the teacher persisted.

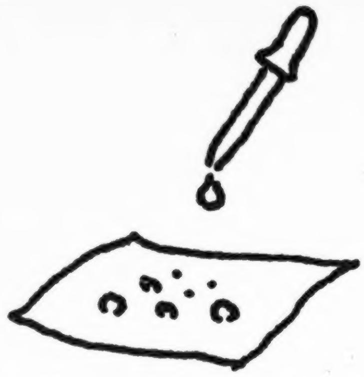
What is the shape of a water drop? (A relatively innocuous question, isn't it?) Round. Not always. Sometimes like a football. After these and other quick responses, the teacher put forward a pointed question as to why no one had mentioned a rectangular drop. The reply to this was, "That's crazy, drops aren't square," and the teacher's response was, of course, "Why?" With the sudden and surprising realization that this couldn't be immediately answered, they were off....

- The most important word in science is "why?"

- Good science teaching does not necessarily involve expensive apparatus. The important thing is to have students actively involved in the problem.

It was decided that maybe the class had better spend some time observing these drops before they tried to ask (or answer) any more questions. Each student was provided with a medicine dropper, a beaker for water, and a square of heavily waxed paper.

The first observations recorded concerned the initial question, shape. There was a lively round of arguments--with much pointing to sketches on data sheets--and the class made a frequency chart of the shapes most encountered. (No one made any surface-volume conclusions at this point, although this did come up later when one boy made a sincere effort to determine why there were more round than oblong drops.)



- Waxed paper varies in its ability to "hold" water; select a triple-waxed brand if possible--one of the plastic wraps may also work.

It didn't take long before a student noticed (aloud) that a drop of water had the property of magnification--so there was a brief interval until all had established that their drops were also so endowed. This seemed a good time to ask another question: "What causes magnification?" There was a large amount of doubt and uncertainty here, and the assignment for the next day was to find out about this magnification. (As is to be expected, many copied reports came in. The discussion of the various items discovered soon made it apparent that copying out of a book doesn't give one knowledge because when a question was asked the reporter couldn't interpret what he'd just read.)

- It is a real problem to help children see that copying answers from a book does not necessarily lead to understanding.

- The concepts of reflection, refraction, concave, and convex mirrors appeared gradually--mainly from reading. These were explored by individuals or groups and then reported back to the class.
- The effect of detergents on surface tension was also a natural outgrowth of this module.
- Usually, the "proper" terms will come from the outside reading.
- Students should not handle mercury--it is toxic.
- The ideas of capillarity, cohesion, adhesion, etc. in woven materials can be shown easily by comparing the

As the students talked about lenses, the idea of magnification based on lens curvature came up ("The book said it was so."). They went back to the waxed paper to see, and trying to get varying curvatures was most interesting. First question: "What should we look at?" They settled on newspaper so that no damage would be done if there were spillage. (A short but most valuable discussion then arose as to how they were going to compare their results, and the group decision was to have everyone look at the letter "e" in the news part of the paper--there had been a flurry of different proposals until someone noticed that the advertising letters were different sizes.)

As they observed and collected data relative to magnification, the boy mentioned earlier reported that he couldn't get his water drop to "stand up" more than a certain distance. His report was confirmed by others, and the next topic just "fell into place." Why? Correlated with it were other questions: "What holds the drop together in the first place?" "There's a force in there." "If you put too much water in the drop, the force breaks down." "But how come only the 'up' force doesn't hold? The edges of the drop are all curved."

The class spent some time attempting to determine if they could measure the maximum height of a water drop--and also the maximum flat-width. (The latter yielded to measurement much more readily than the former!)

During this time, toward the end, the outside reading yielded the information that water drops curve because of surface tension. The class, almost unanimously, asked for an explanation. No one knew. So they all decided to see what they could discover about surface tension for next time. (This included the teacher!)

From the discussion which followed, the class generalized that all liquids are affected by surface tension, and they chose to look at alcohol and mercury. The teacher brought some water, alcohol, and mercury the next day in small stoppered test tubes and asked the students to observe the liquids "as they are."

This was rather contrived, but the reverse meniscus of the mercury offered a good opportunity to study surface tension some more, as well as to introduce the idea of capillary action. Discussion involved: "Why is the water climbing up the side of the tube?"

action of a blotter on water and on mercury.

- Forces
- Cohesion was measured using a balance borrowed from the high school.
- There are many "recipe" books on experiments to show science principles; the wise teacher will use these as springboards, not as dead ends.

"The tube is pulling it." "How?" "I don't know."

Although the teacher didn't expect it, a boy asked, "Would the water go higher up if the tube was thinner?" The teacher didn't know, and said so, but followed this admission of ignorance with a question, "How could you find out?" It was arranged for him to visit the high school chemistry teacher, and there he got some various diameter tubing, down to a very tiny one that the teacher had "pulled out" over a Bunsen burner. His report to the class on capillary action (the term given him by the chemistry teacher) was a high point. (Food coloring was used in the water to let everyone see what was happening.)

The use of A Sourcebook for the Physical Sciences provided some additional ideas and the topics of capillary action, surface tension, adhesion, cohesion were looked into by several groups--in each case reporting back to the class about their findings. (NOTE: The specifics of the experiments which were carried out on these topics are not listed. The Sourcebook provided a number of "germ ideas" which the class groups used or modified in a vigorous fashion to determine all they could about these new ideas. Some of the procedures suggested by the Sourcebook were not practical from an equipment standpoint, and to solve this problem an amazing amount of ingenuity developed.)

The results of these reports led the class into a study of water as a force and of some chemistry to find out more about water.

An examination of the topic readily shows that the particles, structure, interaction, and accumulative schemes are inherent in the material being studied. If the group were more mature, with a better background in science, some exploration into the change, random motion, and equilibrium schemes might be introduced.

Instead of introducing similar examples of the topical development as a basis for teaching conceptual schemes in high school, Chapters 4, 5, 6, and 7 give a conceptual outline of biology, physics, chemistry, and earth science, as they are studied by subject-matter specialists. It is no longer necessary to teach these subjects as unrelated bodies of knowledge. The conceptual schemes provide an effective bridge to tie them together.

With one exception, the foregoing examples were adapted to show how conceptual schemes may be woven into existing course materials. In other words they illustrate the second of our two basic approaches. The primary purpose of the one example showing the development of a conceptual scheme was to provide the basis for an experimental project to study concept development in children. Apparently it was not primarily intended as the basis for a course of study at the various grade levels.

The example that follows, which was reported by Janice Cutler, Senior Research Scientist of the Conceptually Oriented Program for Elementary Science (COPES), shows how COPES selected one aspect of one of the NSTA Conceptual Schemes as the basis for developing science materials for elementary students.

Background of the COPES Project

As noted in Theory Into Action "...Each scheme represents a system of facts, principles and concepts which hopefully can be organized into a sound learning sequence from simple...to complex..." This "hope" has been favorably answered by the initial phase of the COPES project during which time a sequence of concepts was developed leading to an ever-increasing awareness, understanding, and appreciation of one conceptual scheme--the conservation of energy. Selected teaching materials and a Teacher's Guide directed to the teaching of the concepts in this sequence with the K-6 level were produced. The conservation of energy principle was selected as the one to test this approach. It was selected because it pervades all of science, and many of its ideas depend also on concepts within other conceptual schemes such as the kinetic molecular hypothesis. In being restricted to the development of a sequence for one conceptual scheme during this test period, arbitrary limitations had to be imposed on the interplay of this conceptual scheme with related schemes. This will not be the case when the full curriculum consisting of 6 to 10 conceptual schemes is developed. The mutual interdependence of all the schemes would provide a richer and even more logical development of ideas. In addition, in this test period, the inclusion of a particular concept or skill had to be evaluated with respect to its contribution to the teaching of the concepts within the conservation of energy scheme. At the K-6 level, only two main segments in a conservation of energy sequence appeared to be most adaptable to the scheme--that is, the conservation of thermal (heat) energy and mechanical energy.

Description of the Project

The rationale for the ordered structure of the design depends first on the selection of activities that provide the best and most meaningful (to children) examples of conservation of thermal and mechanical energy. The structure of the sequence then reflects the development of those concepts, supporting concepts and skills needed to cope with and fully appreciate the culminating activities. As we proceed from one major "conservation" activity to another, additional concepts must be developed to provide a logical arrangement of "lead-in" activities to the higher order, more sophisticated concepts developed later in the sequence. The classical example of conservation, the Galilean pendulum, was considered as one of the later activities to which we would aim a sequence in the conservation of mechanical energy. Originally, it was felt that since children enjoy pushing or pulling objects and working with mechanical toys, that this might be an appropriate avenue of approach for conservation of energy. However, although the idea of force can be easily developed, the concepts of work or of mechanical energy, as either kinetic or potential, appeared much too abstract to the child to be used in the beginning sections of the sequence. He surely could have verbalized the relationship that a force acting through a distance, F x D, is something we call work. He could have solved problems using this expression. But as a conceptual idea, it is doubtful if it would have much meaning for him in the early stages of the sequence.

We found that the concept of heat energy had much more meaning for the young child. Thus, we set our sights at developing a sequence of activities leading to an appreciation of the concept of conservation of thermal energy prior to the introduction of mechanical energy which would then be interwoven within the sequence.

There were three major examples confirming conservation of thermal energy which we felt could be used in a meaningful way at the K-6 level. In hierarchical order they are (1) thermal (heat) energy is conserved when two samples of a liquid are mixed; (2) the heat energy absorbed to dissolve a salt in water will be released when the salt precipitates; and (3) the heat energy absorbed to break the water of hydration bond will be released when the bond re-forms. The intermediate sections of the thermal energy segment must provide bridging concepts between these major ones. For instance, before entering activities concerned with concepts of solutions, the ideas of the difference in energy between a liquid and its solid has to be considered. Thus, the concept of the role of heat energy and change of state has to be developed, between the major activities of (1) and (2) above, followed by a consideration of what happens to a solid structure of a non-meltable salt when a second component, water, is added to form a solution.

Similarly, the structure of the mechanical energy segment is determined by the more elementary concepts needed to appreciate the concept of conservation in the swinging pendulum. Starting with early concepts of force, leading into that of work, then the more abstract concept of the energy of moving bodies, or kinetic energy, is developed. This is followed by developing the concept of the potential energy measured by the work done on the object or the potential work the object can do. The child is then ready to analyze the energy relationships in the almost ideal machine, the pendulum.

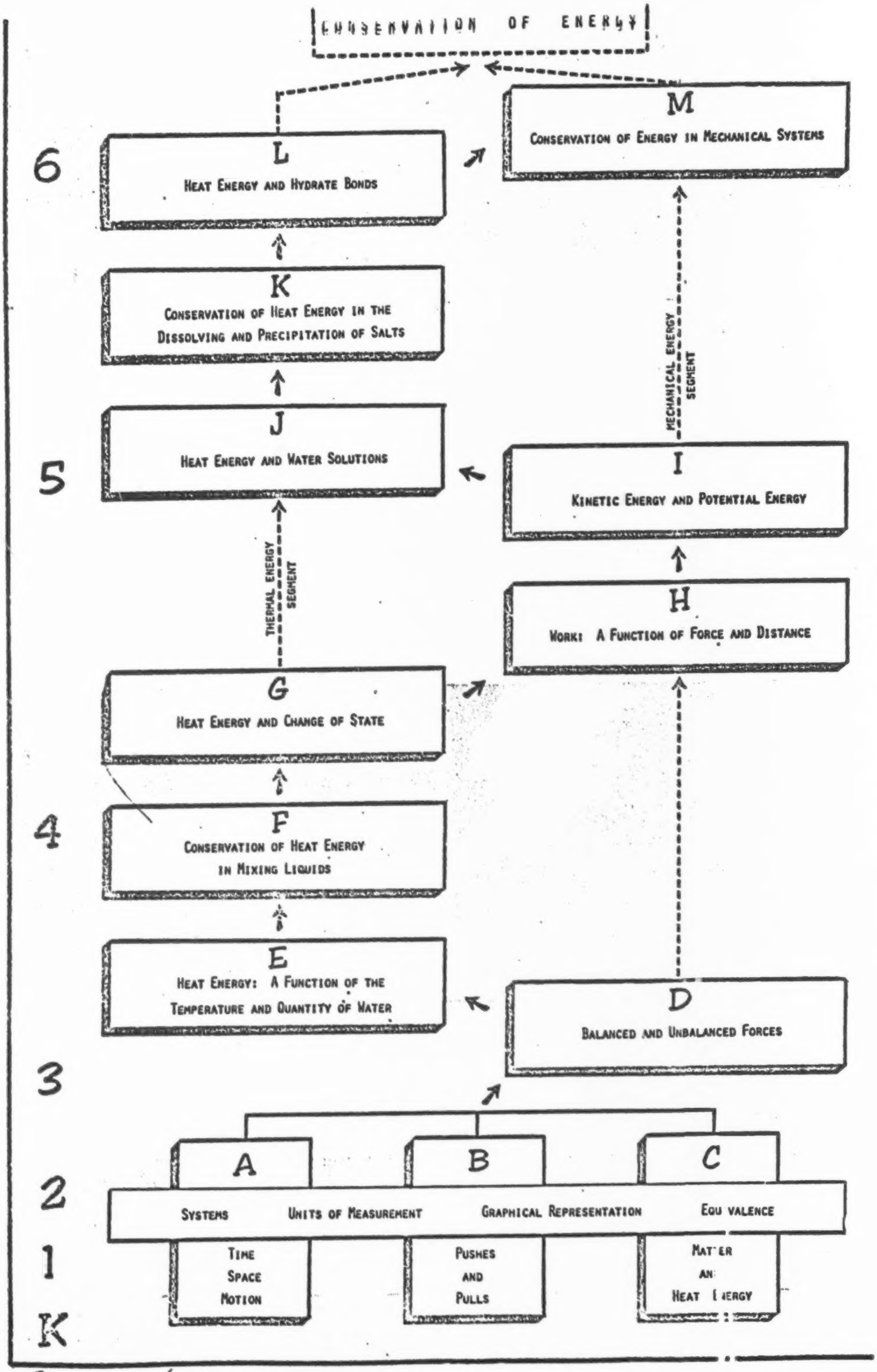
The particular hierarchical arrangement of activities in a conservation of energy conceptual scheme, as illustrated in the accompanying chart, has proven to be effective in classroom teaching for the K-6 level. Logical extensions into the upper grades might include such activities as heats of bond formation within the water molecule, energy or electrolysis compared with fuel cell energy production, and mechanical equivalent of heat. The scope and sequence chart illustrates schematically the organization of all the concepts, major and supporting, used in teaching the conservation of energy scheme. Grade levels at which a particular section was found to be most appropriate with the classes tested are indicated on the left. The title of each section indicates the principal focus of its learning activities. The thermal and mechanical segments are separated--dashed vertical lines connect sections within a segment; solid arrows indicate the direction in which the learning sequence should progress.

Before beginning the main sequence of activities at D, children (K-2) should have experience with the activities in Sections A, B, and C which develop the early concepts and skills needed for the development of the major concepts. These include such concepts as the interaction of heat energy and matter, gravitational force, and motion. As shown on the chart, notions regarding systems, units of measurement, graphical representation, and equivalence are also introduced here.

Since the concept of force is required for an adequate development of Section G in the thermal segment and for later parts of the mechanical segment, Section D is introduced early where it will not only be effective but also will not break the sequence of ideas in the first part of the thermal energy activities. This section deals with all types and sizes of forces, with the concept of balanced forces, and ultimately with the concept of weight as a measure of gravitational force on an object.

The first major activity developed in the thermal energy sequence as mentioned previously, involves the conservation of energy when two samples of liquid are mixed. It was from this activity (in Section F) that the direction of the thermal energy segment was determined. In the activity, the child is involved with a number of related experiments in which he observes the change in temperature when he mixes two samples of a liquid (generally water) each of known amount and known temperature. Prior to this, the child is helped to develop the concept that the "heat energy" of each sample depends on both its volume and temperature (Section E). He is then introduced to a "Heat Energy Unit" (HEU) as the product of volume and temperature of the sample. Multiplication, as well as all other arithmetical operations in the sequence, are worked out graphically. By combining graphically the HEUs the child discovers that he can predict the temperature of the mixture accurately if he assumes that the total heat energy of the mixture is the sum of the individual heat energies--heat energy is conserved. As noted in the chart, experience so far has indicated that the third grade child can proceed through the sequence to the representation of HEUs. It was not until the fourth grade that the concept of conservation of heat energy could be developed with the children.

In Section G, HEUs appear to be "lost" as they go into the "work" of breaking the "binding forces" holding a solid structure together, initially that of solid water, or ice. In essence, a heat of fusion experiment is


CONSERVATION OF ENERGY
6
L
HEAT ENERGY AND HYDRATE BONDS
M
CONSERVATION OF ENERGY IN MECHANICAL SYSTEMS
K
CONSERVATION OF HEAT ENERGY IN THE DISSOLVING AND PRECIPITATION OF SALTS
MECHANICAL ENERGY SEGMENT
5
J
HEAT ENERGY AND WATER SOLUTIONS
I
KINETIC ENERGY AND POTENTIAL ENERGY
THERMAL ENERGY SEGMENT
H
WORK: A FUNCTION OF FORCE AND DISTANCE
G
HEAT ENERGY AND CHANGE OF STATE
4
F
CONSERVATION OF HEAT ENERGY IN MIXING LIQUIDS
E
HEAT ENERGY: A FUNCTION OF THE TEMPERATURE AND QUANTITY OF WATER
D
BALANCED AND UNBALANCED FORCES
3
A
B
C
2
SYSTEMS
UNITS OF MEASUREMENT
GRAPHICAL REPRESENTATION
EQUIVALENCE
1
TIME SPACE MOTION
PUSHES AND PULLS
MATTER AND HEAT ENERGY
K

SCOPE & SEQUENCE CHART

performed. Thus, the concept of the relationship between heat energy and change of state is developed. The concept of reversibility as well as the differences in structure and energy of liquid and solid states of matter, prerequisite to the concepts in Sections J and K are developed within this section.

In Sections H and I, the mechanical energy segment is re-entered. The scientific concept of work as the product of force and distance is developed. Graphical multiplication is also used here. The activities are directed to the early fifth-grade child. Before an appreciation and an awareness of a conservation principle with respect to mechanical energy can be developed at the upper end of the sequence in Section M, activities on what is meant by the two forms of mechanical energy, kinetic and potential, had to be introduced. This was done in Section I. Since the concept of work has been developed operationally in H, the concept of kinetic energy is introduced initially through the work a moving object can do. Children will observe that this energy is a function of both speed and of mass. Subsequent activities lead to a development of the concept of potential energy. The magnitude of the kinetic energy acquired by an object as it rolls down an incline or falls depends on the height from which it is released. At that height the object is said to possess the potential to do work or to be converted into kinetic energy and thus we say it possesses potential energy. Since, in a swinging pendulum, attention will be directed to the interconversion of energies of a steel sphere, these early activities on mechanical energy focus on the use of the sphere as the lifted or moving object. The concept of potential energy is also extended beyond that of gravitational potential to that stored in a stretched elastic band or spring.

The thermal energy segment is re-entered in Section J with an introduction to solutions. What occurs when a second substance, such as water, is added to a solid salt, apparently non-meltable, is considered. Analogies between the liquid state of a melt and a solution are made. Having developed a concept of a liquid solution, we can then lead logically into activities involving supersaturation in Section K. It is possible to keep track of heats of solution because of the unique property of some salts to form supersaturated solutions. First, in a qualitative sense, then quantitatively, the heat energy required to dissolve a salt is found to be released when the salt precipitates. Again, heat energy is conserved. This section of activities also focuses on concepts of reversibility and the differences in energy content of the liquid versus the solid state.

In the next Section, L, the role of heat energy in the molecular realm is pursued. The relationship between heat energy and the molecular bond formed between water and certain salts is investigated and a model of a chemical bond is developed. The behavior of colored hydrated salts serves as an excellent teaching medium for this major concept. The investigation will be concerned on a qualitative lever with the absorption of heat to break a bond followed by its release when the bond re-forms. Again, heat energy is apparently conserved.

It is with this background that the children will begin the last section, M, of activities in the sequence where they will deal with the conversions of energy in mechanical systems. Because of their prior experience with "nose-counting" heat energy inputs and outputs, they should be able to keep track of energy inputs and outputs in mechanical systems.

The sequence within the section is so arranged that the pendulum is the culminating activity. The first activities deal with mechanical systems that are far from ideal, where the work input does not equal the output; i.e., where the potential and/or kinetic energies decrease. Losses can be attributed to the production of heat energy when moving objects collide or when friction effects exist. Frictional effects are minimized when the ideal system is approached; that is, the work output approaches the work input. In such cases minimal losses in potential or kinetic energy are observed. And finally, the pendulum is analyzed. Children will find that the potential energy given to the sphere at the start of its swing reappears at the end of each swing without dimishing appreciably. Thus, mechanical energy appears to be conserved.

With time, however, the pendulum swing will diminish--the machine is not ideal. Children should be prepared to attribute this loss in mechanical energy mainly to the production of heat energy at the fulcrum where a small frictional effect exists between the fulcrum and the string support. Air resistance, of course, also decreases the pendulum's energy. Explanations of this kind indicate that children are on the way toward forming a generalization about the conservation of energy, both mechanical and thermal.

Evidence from the pilot study with sixth-graders strongly indicates that they not only completed the sequence but were able to verbalize interrelationships between mechanical and thermal energies. They were able to apply appropriate analogies from the thermal sequence activities to this final section of the mechanical energy sequence.

Summary

These examples show how various individuals and school committees have used the conceptual schemes as a basis for curriculum development. Much remains to be done in this field. But progress is being made, and encouraging results are beginning to appear.

One of the interesting aspects of committee efforts at using conceptual schemes in curriculum planning is the reorientation of the thinking of many of the individual committee members. Classroom teaching is still largely an individual responsibility. Until the individual teacher can be encouraged to incorporate the philosophy of the use of conceptual schemes as the basis for curriculum planning, the idea will not achieve its full potential for curriculum improvement.

PART II.

CONCEPTUAL ORGANIZATIONS OF BIOLOGY, CHEMISTRY, EARTH SCIENCE, AND PHYSICS

CHAPTER IV

SOME CONCEPTUAL ORGANIZATIONS OF BIOLOGY

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We are committed to the thesis that every American citizen should be educated commensurate with his ability. In keeping with this attitude, we also believe that all educable citizens should be scientifically literate. However, not everyone has reached consensus on what constitutes scientific literacy. One point of view concerning the attributes of the scientifically literate person has been expressed by Paul DeHart Hurd (see Appendix A). We know that the citizenry will not understand the ideas of science or its processes unless appropriate structural and sequenced science materials are studied, the teaching is accomplished effectively, the teacher is well qualified for the task, and the learning environment is stimulating and challenging--and the learner is involved actively with science objects, events, and ideas.

A point of view to which we subscribe suggests that in the process of education we provide science materials, teaching, teachers, and learning environments in which the conceptual structure of the science is transferred to the cognitive structure of the student. Here attention is devoted to conceptual organizations of biology -- a scientific discipline that has undergone revolutionary changes in the last two decades, and is still in the midst of rapid, extensive change. The entire body of knowledge has been and is being restructured, ordered, and sequenced in many different ways by various groups and individuals.

A major effort in biology curriculum restructuring was undertaken by the Biological Sciences Curriculum Study. If one examines the various BSCS publications, he will note, among other things, that the BSCS aimed to develop high school biology materials that would enhance the student's understanding and appreciation of:

a. biological levels of organization of living things;
b. the human body -- its structure and function;
c. diversity and interrelatedness among all living creatures;
d. basic biological problems of evolution, development, and inheritance;
e. biological basis of problems in medicine, public health, agriculture, and conservation;
f. the beauty and, also, tragedy, and drama of life;
g. the historical development of biological concepts;
h. the nature of scientific inquiry, and,
i. the methods and procedures of the scientists.

To this end, the BSCS was guided in its preparation of materials by the following themes:

"Science as Inquiry." The student finds that science is not a completed story but is evolving at an ever-accelerating pace. The student discovers that meaningful data result from planned observations and experiments, preceded by questions reflecting concepts based on existing knowledge. The student learns that scientists are capable of error and that considerable scientific inquiry is concerned with revision and retesting of ideas.

"The Intellectual History of Biological Concepts." In this theme, the history of scientific ideas or concepts is introduced. The teaching of science as inquiry and the point that scientists are individuals are developed. The progression from the concept of function through the concept of homeostasis to the concept of regulation is a good example of historical development and progressive enlargement as concepts are used, tested, and exploited, as this theme is introduced. Using "Invitations to Enquiry," students should receive a realistic and understandable view of science and of scientists.

"Change of Living Things Through Time: Evolution." A coherent account of living things cannot be presented without the story of evolution. Because of the pervasive and comprehensive character of evolution, it is introduced in three ways in the three versions of BSCS. Evolution is interwoven throughout the chapters in the treatment of cellular physiology, ecology, systematics, developments, and diversity. There are specific chapters on descriptive evolution as the history of living things. Finally, there are specific chapters on the dynamics of evolution as a process.

"Diversity of Type and Unity of Pattern in Living Things." Diversity in form is obvious as one observes living organisms, such as the varied morphologies of birds or humans. As opposed to this is the equally obvious unity of living material, as seen in the role of ATP in energy transfer or the significant role of DNA in heredity. Because unity-diversity is both a theme in its own right and an aspect of evolution, it is treated in two ways in the BSCS versions. There are chapters specifically concerned with variety and unity of living things. When feasible, particular diversities and unities are firmly tied to the mechanisms of adaptation through natural selection and of mutation as their originating sources.

"The Genetic Continuity of Life." The need for introducing students to both the aspect of genetic continuity and genetic discontinuity should be self-evident. Basic to our attempts to understand living organisms is an understanding of genetic mechanisms. In such mechanisms lies the answer for development of structure and function, the continuity of species, and the introduction of variations providing the raw material for evolution.

"Complementarity of Organism and Environment." This theme, also, is related to the theme of evolution. In the BSCS versions, two additional emphases are made. First, there is emphasis on the interplay of organism and environment at all levels of biological organization...the molecular as well as the organismal. Second, there is an emphasis on the reciprocal relations of living unit and environment. The organism is not merely a passive recipient of stimuli from the environment. It affects as well as is affected. These ideas can be identified in ecological succession and in predator-prey relationships.

"Biological Roots of Behavior." As this theme is developed, the student is introduced to two aspects of behavior, heredity and environment. Behavior arises not only from the experience of the individual in particular environmental situations but also from the "experience" of its forebears, the stored experience arising from variation and selection in evolution. It is important that the student himself understand that there may be limits to what he can do, limits imposed by his biology.

"Complementarity of Structure and Function." In the treatment of this theme, perhaps, the BSCS versions differ from traditional texts more than in some other approaches. Structure is not considered as an isolated group of parts and pieces to be dissected, named, identified on a drawing, and committed to memory as a series of facts. As presented in the versions, the student recognizes that structure and function are correlated and that the interrelationships between structure and function apply at all levels of organization...from the template of an enzyme to the structure of heart or bone or of the body as a whole. An entire section of "Invitations to Enquiry" is devoted explicitly to the theme of function and to the evidence by which function is inferred. This theme is further expanded in a special laboratory block on the Interdependence of Structure and Function.

"Regulation and Homeostatis - Preservation of Life in the Face of Change." To many, the concepts of this theme are among the most intriguing of biological phenomena. In the development of this theme the student comes to appreciate "dynamic equilibrium" in relationship to change in structure and function. Structures are discussed in terms of flexible characteristics as well as in terms of more constant states. The concepts are introduced in "Invitations to Enquiry," as for example, when feedback control of thyroid and other hormones or other aspects of regulation are discussed.

H. Bentley Glass had this to say, "We hope that biology--and indeed all science--will be presented as an unending search for meaning, rather than as a body of dogma or as a series of taxonomic exercises. Our main objective is to lead each student to conceive of biology as a science, and the processes of science as a reliable method of gaining objective knowledge."

Even though the BSCS themes focus on properties of living things, it is obvious that the "themes" overlap many of the conceptual schemes and processes of science set forth in Chapter Two of this publication. The essence of organic evolution is change--one of the conceptual schemes. Diversity and unity in living things are evidenced by structure--a conceptual scheme. Genetic continuity leads one into several of the conceptual schemes--particles, probability, interaction, change, and structure. Homeostasis is "dynamic equilibrium," hence moves one conceptually into several of the conceptual schemes.

Another conceptual structure of biology was described in Behavioral Science (Volume 3, Number 2, April 1958) according to the following schemes: molecule, organelle, cell, organ, individual, small groups, species, community (ecosystem), and total biota. In each of these categories nine major aspects of structure, equilibrium, and history were developed. This publication was the result of a Conference on Concepts on Biology which was chaired by Dr. Ralph Gerard and sponsored by the Biology Council of the National Academy of Science - National Research Council.

The interrelatedness of these biology concepts to the conceptual schemes in this publication is obvious. Structure and equilibrium are common to both sets. And, if one studies the molecular and cellular structure and function of organs, one is involved with several conceptual schemes--particles, equilibrium, change, and interaction.

The Commission on Undergraduate Education in the Biological Sciences at a conference in St. Louis derived yet another plan for a conceptual organization of biology for use as a guide in developing core biology for undergraduates, both majors and nonmajors. The major conceptual categories were:

1. Molecular Topics. Elementary biochemistry, DNA structure and function, protein synthesis and regulation, properties of enzymes, biochemical synthetic pathways and energy metabolism.
2. Cellular Biology. Cell structure and function: gross and fine structure, physico-chemical organization, energetics, transport, mobility, homeostatic mechanisms. Cell growth and division. Cell differentiation and transformations; clonal variation and development. Evolutionary potential of cells: protisan evolution, origin of multicellularity.
3. Genetics. Mendelianism - historical aspects: discovery and rediscovery of laws and modifications, linkage. Cytological basis of inheritance: miosis mitosis, non-disjunction. Molecular genetics: physical basis of the gene; gene action and regulation; homeostatis, integration in steady-state. Cytoplasmic inheritance: genes and development. Mutation: chromosomal aberration, effects of radiation. Genes in populations: evolution (speciation).
4. Developmental Biology. Plant and animal ontogeny (molecular to gross structural levels); experimental investigation of plant and animal development. Problems: Aggregation (molecular, cellular, multicellular). Directive aspects (induction, regulation, differentiation). Evolutionary aspects.
5. Organismic Biology. Structural and functional organization of selected higher plants and animals; a modern synthesis including (1) facts about the complications of organization of higher organisms, and (2) contemporary heuristic topics such as biological clocks, photo-induction in flowering, electrophysiology, neurosecretion, immune and self-recognition mechanisms.
6. Population and Community. Structure and dynamics. Environmental action and internal reactions; symbioses and competition. Energy flow, homeostasis and succession. Ecological aspects of natural selection.
7. Evolution. Present as a recurrent theme in each of the preceding. In most, cores will also receive, independent, synthetic treatment as well.

Every major conceptual category suggested by CUEBS is interrelated to several, if not all, of the conceptual schemes. For instance, the student engaged in the study of developmental biology is involved with subconcepts and concepts of each of the seven conceptual schemes.

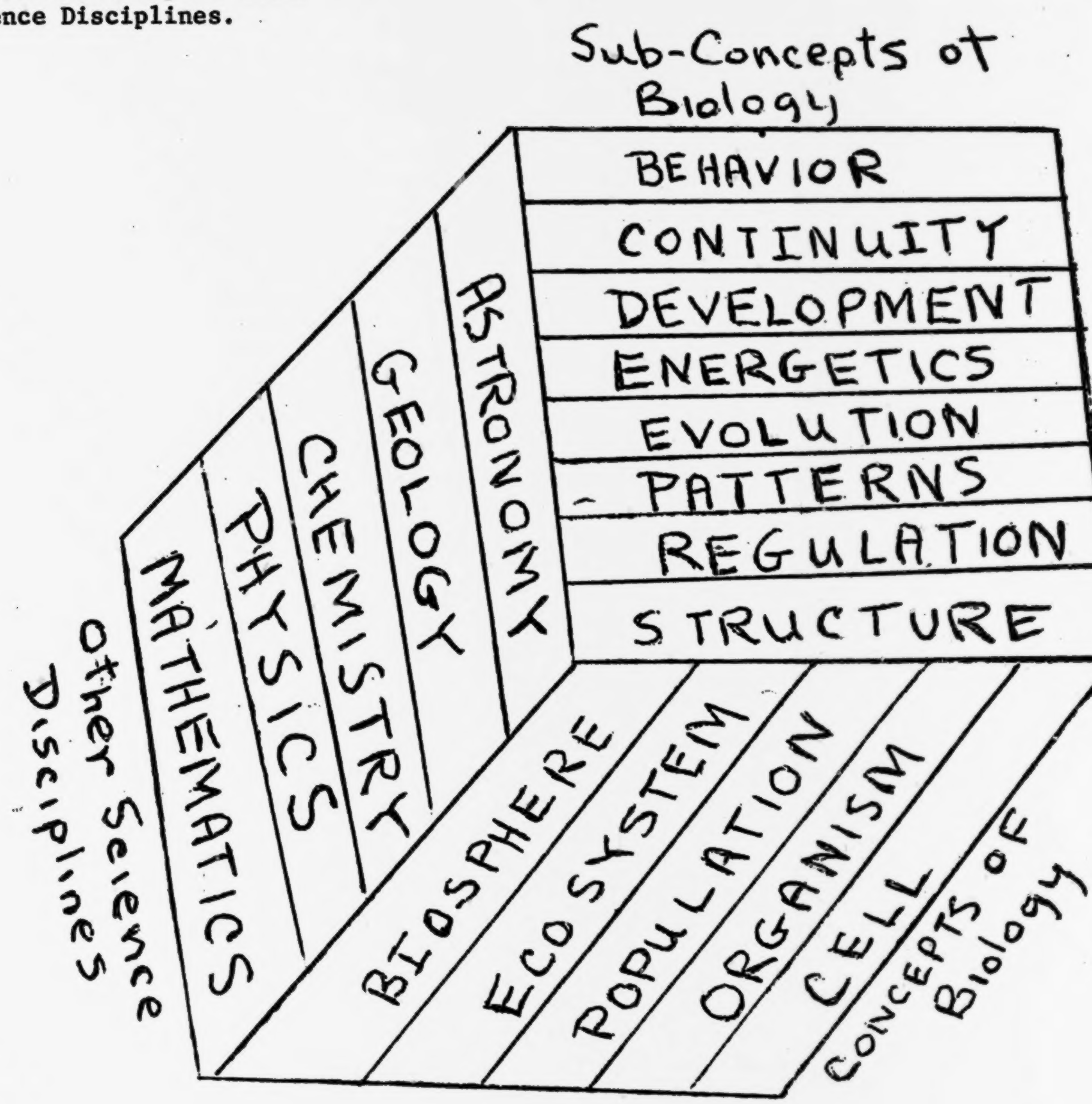
If one examines the literature concerned with the structure of the knowledge in the disciplines of science, it is soon apparent that the knowledge is categorized as ideas, principles, concepts, subconcepts, conceptual schemes, major concepts, generalizations, understandings, expository organizers, comparative organizers, and *ad infinitum.* Further, it is clear that agreement does not exist, among scientists within a discipline, as to the meaning of these terms. For convenience and hopefully both for the sake of simplicity and clarity, we are considering a conceptual organization of biology in terms of concepts and subconcepts. A concept is here used as a large piece of knowledge of biology; a subconcept is a smaller piece of knowledge; third-, fourth-, or fifth-order concepts could be used to delineate smaller and smaller pieces of knowledge. It is often a matter of personal preference and judgment as to hierarchical order one assigns a given concept. But it is obvious that the concept of evolution incorporates more knowledge than does the concept of gene.

We believe that to attempt to interpret all characteristics of life in purely physical-chemical terms is to make obscure some of the most interesting attributes of living systems. For example, metabolism, growth, reproduction, and, in man, thought, self-awareness, and death awareness are unique. On the other hand, it is clear that many functions of living systems can be explained meaningfully only in physical-chemical terms. But it may never be possible to explain behavior of living organisms in purely physical-chemical laws. The interrelatedness of physical, chemical, and biological concepts and subconcepts is a function of the science curriculum. It is not possible to state a concept that is unrelated to any other concept of science. The degree of relationship oftentimes is obscured by man's lack of adequate information about the phenomenon.

SOME ORGANIZATIONS OF BIOLOGICAL KNOWLEDGE

It is possible to order biological knowledge in a variety of ways and to depict the ordering in models which are often useful as guides to the curriculum developer. For this particular organization, five concepts (cell, organism, population, ecosystem, biosphere) and eight subconcepts (behavior, continuity, development, energetics, evolution, patterns, regulation, structure) are used to categorize the knowledge of biology and to show the interrelatedness of these to each other, as well as to other science disciplines.

Figure 12. A Conceptual Structure of Biology and Its Relationship to Other Science Disciplines.


Sub-Concepts of Biology
BEHAVIOR
CONTINUITY
DEVELOPMENT
ENERGETICS
EVOLUTION
PATTERNS
REGULATION
STRUCTURE
ASTRONOMY
GEOLOGY
CHEMISTRY
PHYSICS
MATHEMATICS
Other Science Disciplines
BIOSPHERE
ECOSYSTEM
POPULATION
ORGANISM
CELL
CONCEPTS OF Biology

Another organization, using the same five concepts as in Figure 12, but including eight subconcepts that are similar, yet somewhat different are shown in a model in Figure 13.

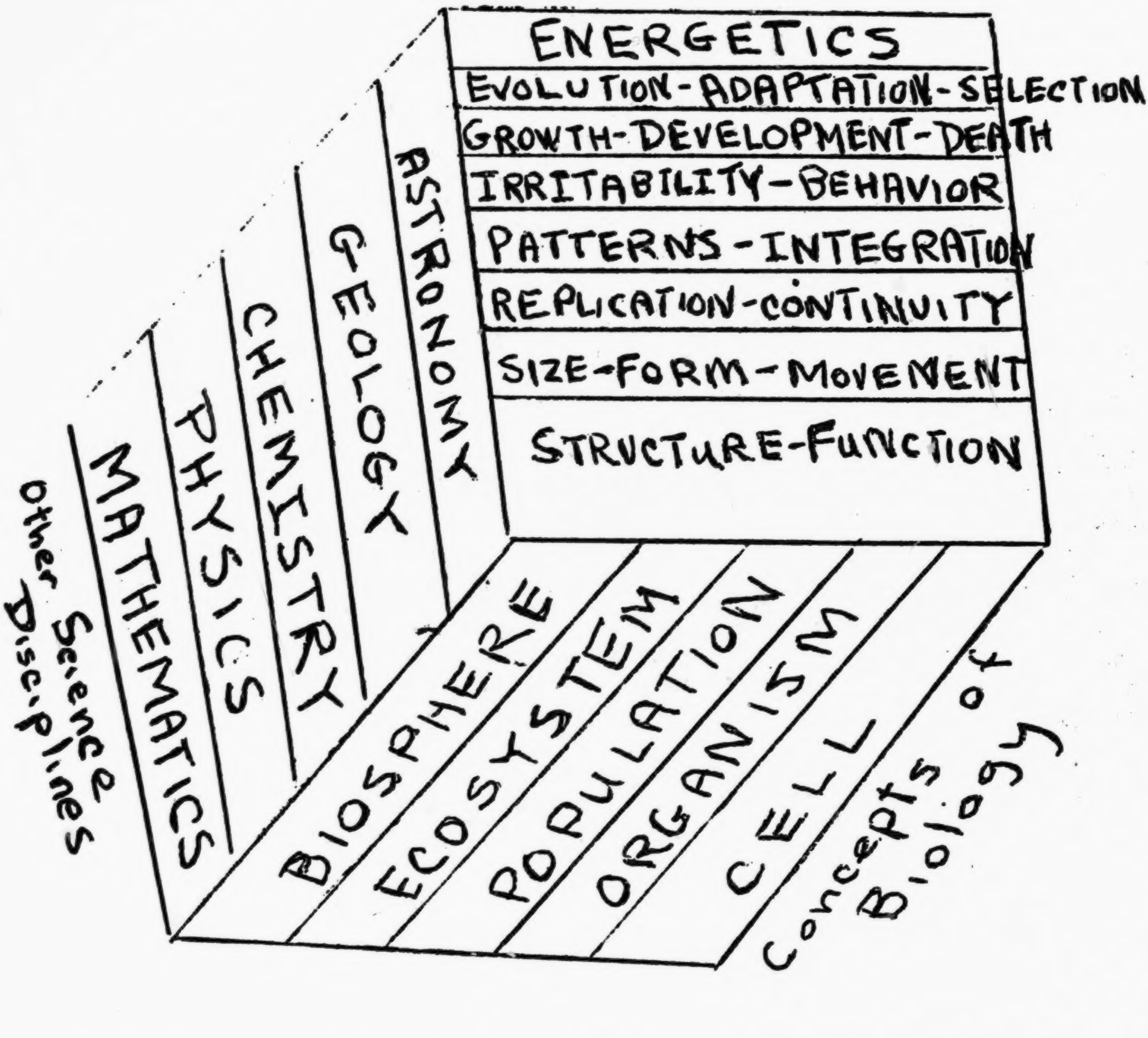

ENERGETICS
EVOLUTION-ADAPTATION-SELECTION
GROWTH-DEVELOPMENT-DEATH
IRRITABILITY-BEHAVIOR
PATTERNS-INTEGRATION
REPLICATION-CONTINUITY
SIZE-FORM-MOVEMENT
STRUCTURE-FUNCTION
ASTRONOMY
GEOLOGY
CHEMISTRY
PHYSICS
MATHEMATICS
Other Science Disciplines
BIOSPHERE
ECOSYSTEM
POPULATION
ORGANISM
CELL
Concepts of Biology

Figure 13. A Conceptual Organization of Biology and Its Relationship to Other Science Disciplines.

Other models of the structure of the knowledge of biology could be developed and the number of concepts and subconcepts might vary some, but the major differences would be in the ordering and sequencing the first- and second-order subconcepts. A sample of second-order subconcepts is shown in the accompanying table.

If one were to use the model in Figure 12 as a guide to the development of learning units in biology, it would become obvious immediately that each of the seven conceptual schemes is, also, involved. For instance, a learning unit on the Life Cycle of the House Fly could focus on the organism-behavior-physics intersects of the model. If so, the conceptual schemes of motion, change, structure, and interaction could be involved. The curriculum materials developer then has to face the question: At which level of sophistication or abstraction is the learner able to conceptualize structure, motion, change? And, what is the next most logical step for the learner as he deals with these conceptual schemes?

The conceptual organization shown in Figure 13 could be used as a guide to develop another learning unit on the Life Cycle of the Fly. The population, energetics, and chemistry intersects might be used in the instance. Thus, focus could be placed on the conceptual schemes of equilibrium, interaction, and probability. The level of abstraction which the learner could deal with these concepts, subconcepts, and conceptual schemes would depend on the learners' prior experiences with these and related concepts, as well as with experiences on the processes of science.

Models such as these are useful to the development of coordinated, sequenced curricular materials in biology. For example, one must decide what knowledge in the "Cell-Structure-Chemistry" and "Organism-Evolution-Geology" cubes (Figure 14) is essential to include in a biology or science curriculum, and, also what is nonessential and hence not to be included. Each cube from the model would be considered similarly.

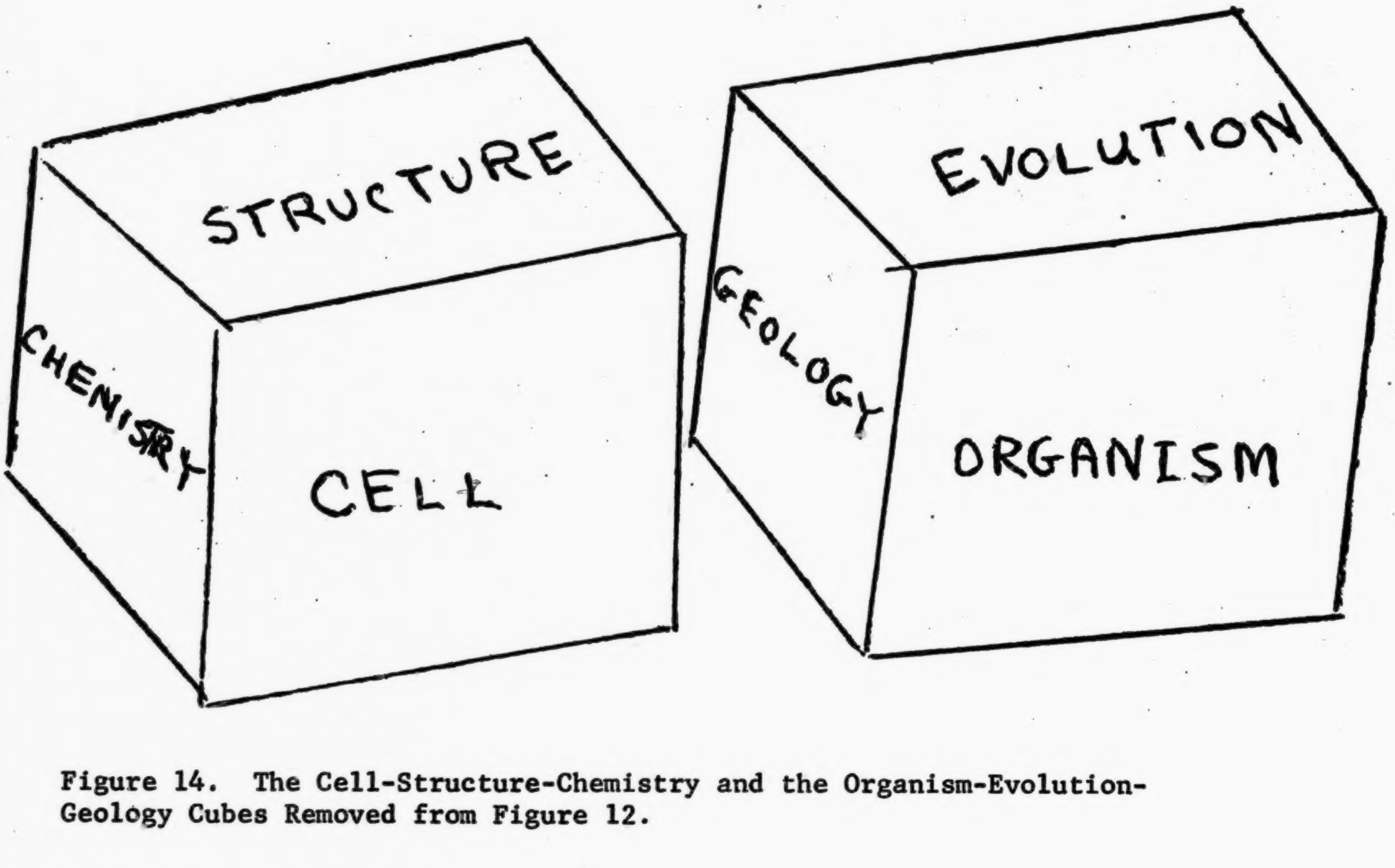


Figure 14. The Cell-Structure-Chemistry and the Organism-Evolution-Geology Cubes Removed from Figure 12.

In addition to considering the knowledge to be included in each cube, one must decide on the order and sequence in which the student should learn this knowledge. For example, in a K-12 science curriculum, what components of the "Cell-Structure-Chemistry" cube should be learned and at what level of sophistication at a given grade level, or at each grade level?

Furthermore, the curriculum developer must consider, in addition to the structure of the knowledge, such components as: the processes of science; the developmental stage of the learner; the learning environment; the competences of the teacher; the relevance of biology to other sciences, to the social sciences, to the humanities, and to other parts of the total curriculum; and, perhaps most important of all, the behavioral changes one hopes to bring about in the student.

The development of a biology curriculum is complicated and requires a great deal of continuing expertise, for, at best, a given biology curriculum is transient. A biology curriculum must remain dynamic if it is to be effective.

Table of Second-Order Subconcepts of Biology
Arranged in Eight First-Order Subconcepts

Subconcept 1: Behavior

1. Social
2. Reproductive
3. Escape
4. Food-getting
5. Tropisms
6. Imprinting

Subconcept 2: Continuity

1. Cell Theory
2. Cell Division
3. Differentiation
4. Sexual Reproduction
5. Vegetative Reproduction
6. Heredity
7. Genes
8. Genetic Code

Subconcept 3: Development

1. Plant
2. Invertebrate
3. Amphibian
4. Mammal
5. Tissue
6. Organ System

Subconcept 4: Energetics

1. Cell Physiology
2. Respiration
3. Photosynthesis
4. Digestion
5. Excretion
6. Organic Molecules
7. Nucleic Acids
8. Biogeochemical

Subconcept 5: Evolution

1. Mutations
2. Adaptation
3. Selection
4. Genes
5. Chromosomes
6. Species
7. Population
8. Origin of Life
9. Man
10. Fossil Record

Subconcept 6: Patterns

1. Unity
2. Diversity
3. Classification
4. Protists
5. Plants
6. Animals
7. Man
8. Growth
9. Response
10. Differentiation
11. Populations
12. Biogeographical Cycles

Subconcept 7: Regulation

1. Cell
2. Plant
3. Animal
4. Population
5. Community
6. Reproduction
7. Growth
8. Differentiation
9. Integration
10. Heredity
11. Species
12. Biogeochemical Cycles

Subconcept 8: Structure

1. Macromolecule
2. Microorganisms
3. Plants
4. Animals
5. Populations
6. Cell
7. Tissue
8. Organ
9. Organ System
10. Organelle

CHAPTER V.

CHEMISTRY LOOKED AT CONCEPTUALLY

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A conceptual ordering of chemistry is not readily available in the literature. It appears that only a few scientists have recorded any extended thinking on the subject. It is the intention, then, of this chapter to summarize a way of looking at chemistry in the light of the concepts described in Chapter I. The major concepts of space, time, energy, and matter are central to any chemical investigations.

In considering the nature of chemistry, it is helpful to distinguish two kinds of activities characteristic of chemists. (1) There are those things that chemists do in the laboratory and in the field. Those things representative of the doing of chemistry will be referred to as operational. Only a few of the most important operational items will be presented here. It is these operational features that probably distinguish chemistry from the other sciences. (2) Another set of activities has to do with what chemists think, and these activities are referred to as conceptual. In general, the conceptual activities are concerned with the operational. The operational provides information (data), and the conceptual provides ideas by means of which the data are interpreted. Together, the operational and conceptual provide understanding.

The operational character of chemistry provides the basis for classifying it as an activity distinguishable from other disciplines. The conceptual character of chemistry will be related to the concepts described in Chapter II: particles, structure, interaction, change, random motion, probability, and equilibrium.

Before taking up the description of the operational and conceptual nature of chemistry, it will be useful to refer briefly to some other recent attempts to organize chemistry.

Recently a study of chemistry in the United States was made for the President's Science Advisory Committee and published in what is called the Westheimer Report. A brief summary of the Westheimer Report with reference to the conceptual structure of chemistry is given in the preface to the book Basic Principles of Chemistry by H. B. Gray and G. P. Haight; W. A. Benjamin, Inc., 1967, page v, and is quoted below:

> One of the most urgent problems is to find a viable classification of the fields of chemistry. The old categories of physical, organic, inorganic, and analytical chemistry have steadily merged so that we now have an assortment of combination names such as physical organic, physical inorganic, organometallic,

> electroanalytical, and so on. The challenge today is to reclassify the fields of chemistry along the natural borders of contemporary research. This reclassification must also provide a framework in which the teaching of chemistry can be performed in a most efficient and exciting way.
>
> In our opinion an advance of truly major proportions has already been made by the recently published Westheimer Report. The suggestion made by this committee of distinguished scientists is to realign chemistry according to contemporary research fields, of which the major areas are structural chemistry (the study of structure of matter, with emphasis on electronic and atomic arrangements), chemical dynamics the study of atoms and molecules in the course of chemical transformations), and chemical synthesis.

These suggestions from the Westheimer Report are most interesting. However, it is not at all clear that contemporary research necessarily defines the conceptual structure of the discipline. Presumably research chemists are motivated to work most on those aspects of chemistry that appear unresolved but amenable to improved understanding with the technical means at hand. It would be most unlikely to find that the distribution of unresolved issues was uniformly related to any reasonable set of features in the conceptual structure. Contemporary research should, therefore, be related to but not descriptive of any underlying conceptual structure characteristic of chemistry.

A conceptual approach to the undergraduate chemistry curriculum has been developed at Earlham College, and is described in a paper by Bakker, Benfey, Stratton, and Strong (Journal of Chemical Education, 41, 133-5, 1964) by the following quotation:

> Our approach to instruction in chemistry is consistent with a statement by Jerome Bruner (The Process of Education, Harvard University Press, Cambridge, Mass., 1960, p. 11):
>
> "Students perforce have a limited exposure to the materials they are to learn. How can this exposure be made to count in their thinking for the rest of their lives? The dominant view among men who have been engaged in preparing and teaching new curricula is that the answer to this question lies in giving the students an understanding of the fundamental structure of whatever subjects we choose to teach. This is a minimum requirement for using knowledge, for bringing it to bear on problems and events one encounters outside the classroom..."
>
> The development in students of an understanding described by Bruner would seem to require a curriculum based on a set of major concepts. These we have formulated in the following way:

> Substances are characterized by structures interpreted in terms of electrons and nuclei as the structural units.
>
> Chemical reactions can be interpreted as interconnected structural and energetic changes.
>
> The direction and extent of a chemical reaction can be related to energy and entropy changes.
>
> The rate of a chemical reaction can be interpreted by a mechanism which describes the path of the reaction.
>
> Concepts, however, have significance only as they serve to impose regularities on diverse empirical data. Each chemistry course, therefore, has been designed to show how certain sets of observations can be interpreted by means of a particular conceptual scheme.

The only other formal attempt at a conceptual structure of chemistry appears to be one written by E. F. Caldin under the title The Structure of Chemistry in Relation to the Philosophy of Science published by Sheed and Ward, London, 1961. He divides the fundamental concepts of chemistry into four categories: (i) pure substances, (ii) elements and compounds, (iii) molecules, atoms, and sub-atomic particles, and (iv) energy. The discussion by Caldin is worthy of considerable study. In it he stresses the need to distinguish between the empirical and the theoretical aspects of the subject. His treatment is brief and suggests several interesting possibilities, but more detail is needed to make clear the nature of the structure.

One of the more intriguing ways of characterizing chemistry was made by Max Planck in his book Thermodynamics (p. 24, footnote):

> To sum up shortly, one may say that physical changes take place continuously, while chemical changes take place discontinuously. Physics deals chiefly with continuous varying quantitites, while chemistry deals chiefly with whole numbers. (See also p. 222.)

In trying to formulate a conceptual structure for chemistry, we will consider the operational and the conceptual separately.

Operational Character of Chemistry

A simple, probably too simple, view of the operations of chemists is that chemists are exploring and trying to understand what happens when materials are mixed together. For any set of materials mixed together, two types of changes are observed -- one type occurs within the system of materials themselves, while the other occurs outside the system of materials. For example, the burning of magnesium in oxygen results in the disappearance of the magnesium and the oxygen and is accompanied by the appearance of a white powder, magnesium oxide. All of these changes described occur within the system. As the magnesium and oxygen change, it is possible to have things so arranged that other changes occur outside the system. Thus a piece of photographic film may be caused to darken or the temperature of some object may rise, even though the film or the temperature-sensitive object may be some distance from the magnesium-oxygen system. Along with the operational characteristics described, the chemist makes use of a great variety of property measurements.

OPERATIONAL CHARACTERISTICS -- INTERNAL CHANGES

There are essentially two kinds of operational characteristics. One kind is based on subdivision of samples and is called analysis. The other kind is based on assembling samples and is called synthesis.

ANALYSIS

I. Subdivision of a material by cutting into small pieces

a. Heterogeneity

Small pieces differ in one or more properties such as density, color, hardness, heat capacity. The original material is said to be heterogeneous and separable into two or more portions, so that each portion is uniform when subdivided. A heterogeneous material is called a mixture.

b. Homogeneity

The small pieces do not differ in properties when compared. The original material is said to be homogeneous. Every heterogeneous material can be subdivided and sorted into two or more homogeneous portions.

c. Phase

A homogeneous portion of a system is called a phase.

II. Subdivision by distribution between two or more phases. A homogeneous material may be altered by cooling, heating, compressing, or expanding so that a second phase is formed. Alternatively a second material may be mixed with the material to be examined so that a second phase is formed. In either event the material is found to distribute itself between the two phases. Two different types of distribution are observed. For one type the material is called a solution and for the other a substance.

a. Solution

The material distributes itself in a non-uniform way. Thus sea water when heated produces a gas phase from the liquid phase. As the gas phase forms, the liquid phase becomes more dense; its boiling point rises; its freezing point first declines then rises; and many other changes occur. The sea water distributes between phases in a non-uniform way. Such a material is called a solution. Whether it be solid, liquid, or gas is of no consequence for the definition.

b. Substance

The material distributes itself in a uniform way. Thus the gas phase obtained from sea water may be cooled or compressed to produce a liquid or even a solid. If the gas phase remains unchanged in properties as the conversion takes place, then the material distributes itself uniformly in the sense that any portion of the material transferred from gas to liquid behaves in the same way as does that which remains. A slightly more complex example is provided by calcium carbonate. When heated, a gas and a solid are produced simultaneously, the conversion of a portion of a calcium carbonate sample does not alter the behavior of the remainder. A rather different type of situation is provided by the addition of small amounts of hydrogen chloride gas to ammonia gas with the formation of a solid phase. The addition of hydrogen chloride gas and the formation of a solid has no effect on the ability to form a solid from any remaining ammonia. Thus the ammonia distributes itself uniformly between the gas and solid phases. A material that distributes itself uniformly between phases is called a substance.

c. Every homogeneous material is either a solution or a substance. All heterogeneous materials are sets of solutions and substances. In general, a material that distributes uniformly between one pair of phases but non-uniformly between another pair is considered to be a solution rather than a substance.

d. Fractionation

In general, the distribution of a solution between phases results in the more or less complete separation of the solution into a set of two or more component substances. This process is called fractionation.

e. Composition

The description of the nature and relative amounts of component substances derived from a solution is called the composition of the solution.

f. Invariance

A substance may be considered to be unchanged or invariant with respect to distribution between phases.

g. Analysis

When an initially homogeneous material is converted into two or more separate phases the process is referred to as analysis. More loosely any series of operations that provides information about the composition of a material is called analysis.

SYNTHESIS

The mixing of two or more substances together with any other desired operations such as heating, cooling, irradiation, grinding, addition of solvent, evaporation, or condensation can lead to the formation of new substances. The formation of new substances is called synthesis. As a result of mixing and other operations, one of two possibilities is observed as the final result.

I. -Heterogeneous Product

a. Mixture

The final phases are identical with the initial phases and the mixing process is said to produce no change. There are two or more final phases with at least one different from either of the initial phases. For either result the product is called a mixture. When one or more phases are formed different from the initial phases, there are two possible types of phases. They are described in the next section.

II. Homogeneous Product

a. Solution

A phase formed by the mixing of two substances has properties that vary in magnitude as the relative amounts of the initial substances vary. A phase of variable properties is called a solution. If a single phase forms for all relative amounts of the initial substances, the substances are described as completely miscible. If a single phase forms over only a limited range of relative amounts of the initial substance, the solution phase at the limit of the range is called a saturated solution.

b. Compound

A phase formed by the mixing of two or more substances has properties that remain fixed as the relative amounts of the initial substances vary. If, for one particular relative amount, the new phase comprises the entire system, it is called a compound. A compound is always a substance.

c. Chemical Element

There are millions of substances known, and nearly all of them are compounds. Those substances which have never been produced as the sole product of mixing two or more substances are called chemical elements. There are about 104 chemical elements known at the present time (this ignores isotopes).

d. Composition of Compounds

Each compound can be formed from a set of elements. The description of the kind and relative amounts of the elements used is called the composition of the compound.

e. Composition of Objects

Every object found on the earth can be considered composed of a set of elements.

f. Invariance

Each compound is an invariant combination of elements. For a solution the properties and composition can be manipulated over a considerable range by simply varying the relative amounts of the initial components used to form the solution. By contrast the properties and composition of a compound are characteristic of the substance and not altered by varying the relative initial amounts of the elements used to form the compound. The composition of a compound also remains constant when the temperature is varied. The invariant behavior is sometimes referred to as the law of definite composition.

g. Synthesis

Compound formation is referred to as synthesis. The simplest example is the conversion of two or more substances entirely into a single substance. For example, the formation of water by mixing hydrogen and oxygen.

INTERACTION-REACTION

The mixing of two or more substances may lead to the formation of a new phase, and, in that event, the new phase is different from either substance. However, it is possible to compare the properties of the new phase with the properties of a system of substances before any of the new phase is formed. The properties compared may include such items as: mass, volume, density, color, hardness, temperature, and many others. Property comparison reveals two types of behavior: noninteraction and interaction. An important special type is called reaction but is really one type of interaction.

I. Noninteraction

If the property comparison reveals no differences before and after the new phase forms, the initial components are said to exhibit noninteraction. Examples are provided by the mixing of helium gas and neon gas or liquid hexane and liquid heptane.

II. Interaction

If the property comparison reveals a difference before and after the new phase forms, the initial components are said to interact. Interaction includes some solution formation processes and all compound formation processes. Examples are provided by the mixing of ethanol and water or hydrogen chloride and ammonia.

III. Reactions

a. Among interactions there is a special set of phenomena called chemical reactions. When the interaction is characterized by a fixed relationship among the amounts of interacting substances, then the interaction is called a chemical reaction. Compound formation is one example of chemical reaction.

b. Stoichiometric Ratio

The ratio of the amounts of the substances in a reaction is called the stoichiometric ratio.

c. Compound Composition

The stoichiometric ratio for the reaction which forms a compound from its elements is referred to as the composition of the compound.

d. Invariance

The stoichiometric ratio is an invariant property of a system of reacting substances.

e. Discreteness

A system of substances may exhibit more than one stoichiometric ratio, but in such cases the stoichiometric ratios cannot be changed continuously from one to another. In general, a series of stoichiometric ratios for a set of substances can be represented by the several products obtained by multiplying a single number and a series of integer multipliers.

EQUILIBRIUM

When the mixing of two or more substances leads to the formation of new substances, it is generally observed that only a portion of the initial substance has been converted even though no evidence of further change can be found. The following set of characteristics is commonly observed and leads to the operational notion of equilibrium. Equilibrium as used by chemists has a number of features entirely consistent with those that the physicist considers in mechanics. In addition to these more physical features, there are others that are characteristically chemical. Chemists often refer to dynamic chemical equilibrium as the behavior characteristic of chemistry.

I. Equilibrium Characteristics

a. Stability: The state of the system does not change.

b. Incompleteness: The system in its final state includes both initial substances and final substances.

c. Reversibility: Two different sets of initial components can react to form a system with the same set of final components.

d. Sensitivity: Disturbances in concentration, pressure, or temperature may each be accompanied by changes in the state of the system which reduce the magnitude of the initial change in concentration, pressure, or temperature.

e. A system with the above four characteristics is said to be in a state of equilibrium.

II. Dynamic Equilibrium

a. In general, variation in the size of a phase does not alter equilibrium state.

b. The addition of more of a phase containing a suitable identifiable but non-reactive tag leads to the tagged material distributing itself spontaneously through the various phases or components in equilibrium. A system that is capable of distributing one component through several phases is said to be in a state of dynamic equilibrium.

III. Dynamic Chemical Equilibrium

a. For some dynamic equilibria the components of the system are related by stoichiometric ratios, and the system is said to be in a state of dynamic chemical equilibrium or more simply chemical equilibrium.

b. All chemical equilibria are dynamic.

c. The equilibrium between a liquid substance and its vapor or its solid need not involve a stoichiometric ratio, and is often spoken of as physical equilibrium.

d. A chemical equilibrium is one type of the much more general class of equilibria that may, in addition to chemical, involve electrical, mechanical, radiation, or other phenomena and including those that are static as well as dynamic.

CONCEPTUAL CHARACTERISTICS OF CHEMISTRY

The conceptual characteristics of chemistry comprise a set of ideas that has been invented and developed over the years. This set of ideas is intended to provide a logical means of connecting the operational characteristics. Although the set of ideas is an extensive one, it is not yet entirely competent to connect all the information that is available. The long-range goal is to connect not only the diverse "facts" of chemistry to one another, but also the phenomena of chemistry with all other phenomena, both physical and biological.

I. Particles

The idea that matter is best thought of as composed of particles implies that matter behaves as if it is discrete rather than continuous. The central operational indication of discreteness in chemistry is the stoichiometric ratio. Closely related are such phenomena as

Faraday's laws of electrolysis, the unitary character of electric charge, and line spectra. In a general way, particles as ideas are closely related to observations that indicate invariant or fixed properties. Different kinds of particles are introduced to deal with one or another type of fixed property.

a. Atoms

The mass relations that characterize the stoichiometric ratios, and in particular the formation of compounds from elements, are described by assigning an atom with a characteristic mass to each chemical element. The characteristic mass is referred to as the atomic mass or the atomic weight.

b. Molecules

The volume relations that characterize reacting gases are described by assigning a molecule as the structure unit of a gas. For low gas pressure it is assumed that equal volumes of different gases contain identical numbers of molecules. Each molecule has a characteristic mass.

c. Ions

The flow of charge through chemicals exhibits several relations as well as the movement of material. These relations are dealt with by assigning ions to be the units of charge flow in materials. In general, an ion can be regarded as an atom or molecule bearing an electric charge.

d. Electrons and nuclei

The interactions that characterize the mixing of chemicals are dealt with by assigning electrons and nuclei. Electrons are present in all matter and are everywhere the same, with each electron being a unit of negative charge. Nuclei are likewise present in all matter and are positively charged, but each element is represented by a different characteristic set of nuclei all having the same electric charge. At the most fundamental level it is differences in nuclear charge and the distribution of nuclei that mediate and control the differences among the various elements and the compounds that they form.

II. Structure

Chemicals are three-dimensional objects, and the appropriate structures are therefore considered to be three dimensional. Geometrical relations therefore apply. The most common geometrical relations applicable to chemistry are probably those represented by tetrahedra and octahedra. However, other geometrical figures and their corresponding symmetry properties prove useful, too. The idea that each sample of a chemical can be thought of as a structure is probably one of the most useful ideas developed by chemists. In some ways the use of the idea of structure can be said to distinguish chemists from other scientists. Structures are formed by assemblies of electrons and nuclei. These assemblies are held together by electric forces operating between the negatively charged electrons and the positively charged nuclei.

a. Bonds

In a structure the arrangement of electrons is often such that a few electrons lie along a line connecting two nuclei. These electrons are then said to constitute a bond or link holding the system together. It is customary to recognize three bond types: ionic, covalent, and metallic. However, in all cases the bond arises from electrostatic interaction.

b. Valence

The joining of nuclei and electrons does not go on indefinitely but only in certain limited ratios. These limiting ratios are often referred to as valence. Thus an oxygen atom usually joins with two hydrogen atoms, and oxygen is said to have a valence of two. However, the valence of an element can vary as conditions are altered.

III. Interaction

In the operational section interaction was introduced as a description of empirical behavior of substances. Conceptually several kinds of interaction are important to chemists.

a. Electrostatic

Substances are viewed as assemblies of electrons and nuclei. These electrons and nuclei interact electrically.

b. Motion

Particles also interact because they collide with one another and transfer energy from one to another.

c. Radiation

Even separated by distance, substances may interact (e.g., photographic film and flash bulb). This type of interaction is thought of as the result of energy transferred by radiation. Radiation includes light, heat, X-ray, and many others.

IV. Change

The central phenomenon of chemistry is that of the chemical reaction, which is an example of change. Substances assembled in a system (reagents) can be arranged in such a way that the initial substances disappear to be replaced by a new set of substances (products).

Chemists are interested in this phenomenon as a means to produce material of desirable characteristics from others that are less desirable in themselves. They are also interested in understanding which changes are possible and which are not. Through studies of the time required for a given change to be completed, chemists attempt to work out detailed mechanisms by which the particles of matter are thought to rearrange themselves to correspond to the change from reagents to products.

In general, change is always in a direction that leads to an increase in total entropy. The total entropy can be regarded as a result of the way that energy is distributed in the system. Change can occur in a chemical system only as a consequence of random motion. The possibility of changing the structures of chemicals and their arrangement within a system is entirely the result of random motion within the structures.

V. Random Motion

Chemicals, when mixed, exhibit not only certain invariant properties but also changes. So although each structure is imagined to be a fixed entity, it is also a changeable entity. The changes are imagined to be the result of random motion of the particles that form the structure. There are three forms of this random motion. Random motion is a key part of kinetic molecular theory.

a. Translational Motion

In the simplest case, an ideal gas, the molecules are assumed to possess nothing but translational motion random as to speed and direction. The fraction of the molecules that possess any particular velocity is described by statistics in the form usually referred to as the Maxwell-Boltzmann equation. Changes in the average translational motion require energy transfer between the gas and its surroundings. Collisions between moving molecules and the container walls produce gas pressure.

b. Rotational Motion

Molecules with two or more nuclei rotate in a random fashion. Changes in average rotational motion require energy transfer. Rotational motion does not contribute to gas pressure but does contribute to heat capacity.

c. Vibrational Motion

Systems of nuclei connected by attractive forces vibrate against one another. The vibration involves both kinetic energy and potential energy. Changes in the average vibrational motion require energy transfer. Vibrational motion does not contribute to gas pressure but does contribute to heat capacity.

d. Temperature

Each system can be represented as an amount of energy distributed among the three forms of random motion. The nature of the energy distribution is controlled by the temperature or, alternatively, the temperature is the energy distribution. In the simplest system, an ideal gas, the absolute temperature is proportional to the average translational energy. At high temperature, translational energy is likely to be the more important part of the total energy than is rotational or vibrational. At low temperature, matter is in solid form, and vibrational energy is likely to be more important than translational and rotational energies.

e. Energy Distribution

In any given system at a given instant there will be some characteristic distribution of energy. For an isolated system the only observable changes are those that lead to a more probable energy distribution. The most probable energy distribution is that one for which all energy forms are equivalent. In general, vibration energy is less probable and hence not equivalent to the other forms.

f. Energy and Structure

When electrons and nuclei interact to form a structure,vibration energies are introduced. Therefore, structure can be regarded not only as an arrangement of particles but also as an energy distribution. A chemical reaction can be viewed both as change in arrangement of particles and also as a change in the distribution of energy.

VI. Probability

Random motion of the particle goes on continuously in any material system. The random character of the motion means that the distribution of the particles at any instant can be described in terms of probability analysis. A central feature of chemical reactions is the fact that a reaction goes in one way for a given set of conditions so that this one way is observed to be a preferred way. However, the motions and interactions of the particles are assumed to be reversible so that one direction is not to be preferred over another. A probability distribution provides the means whereby preferred direction can be superimposed upon the reversible character of the underlying motion. The preferred direction of change for a system of many particles is always from an arrangement of low probability to one of high probability.

a. Large Numbers

A characteristic feature of most chemical systems is the idea that a large number of particles is involved. Chemists find it convenient to compare reactants on the basis of the number of particles present. For the comparison it is usual to take

32 grams of oxygen gas (or 12 grams of carbon) and say that any sample containing as many particles as there are molecules in 32 grams of oxygen is one mole. A mole of particles is found by measurement to be approximately 6 x 10^{23}. Even a micromole of particles is a number of prodigious size compared to our ordinary experiences with countable objects.

b. Distribution

Large numbers of particles moving at random result in every conceivable arrangement being present in a system. At any instant some particles will have zero motion while others will be moving at high speed and, of course, all directions of motion will be represented. The whole assembly can be represented as a distribution of speed, of direction, of orientation, of energy, and of momentum. For some problems an average value can be used to describe the distribution while for others a more detailed description is necessary. One example of the significance of a distribution is provided by the observation that a drop of water placed on a hot surface does not evaporate all at one instant but rather slowly as the low energy molecules are raised in energy sufficiently to permit separation from their neighbors.

c. Direction of Change

To produce a chemical reaction, the chemist assembles a set of reactants. This assembled set considered as a distribution will have, in general, a relatively low probability distribution. As the particles move at random, all conceivable distributions are produced, and the most probable one will be the final distribution of the particles in the system.

VII. Equilibrium

The final state of a system of reacting substances is referred to as the equilibrium state. As the final state of a system in the laboratory, operational criteria can be given for the experimental recognition of equilibrium. In a chemical system equilibrium can be imagined to be a steady state achieved by two or more reactions proceeding simultaneously, so that the products of one reaction are the reactants for the other. A steady state results when the rates of the two reactions are equal. Alternatively, the equilibrium state is reached when no further increase is possible for the entropy of the system and the surroundings together. The various interpretations of the equilibrium state can also be brought together through the idea that equilibrium is achieved by an arrangement of maximum probability.

CHAPTER VI

AN EARTH SCIENTIST'S VIEW OF THE CONCEPTS OF SCIENCE

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As a participant in the group discussions which produced "Theory into Action" and this revision, I can wholeheartedly endorse the conceptual schemes presented in Chapter II. However, I am an earth scientist, somewhat traditional in my overview of science, and I prefer a graphic presentation of even such abstractions as conceptual schemes. The following is my interpretation of what I think the conferees have agreed upon. No two of us would say these things in precisely the same way nor present them in the same graphic form. Since the first conference, I have found that many teachers appreciate a graphic and reworded presentation of the conceptual schemes. Hopefully some readers will find this presentation helpful.

At the center of the diagram is an indication that science is concerned with the study of objects both living and nonliving. The nature and behavior of objects may be understood in terms of matter, energy, forces, motion, time, and space. These are the major concepts of science. Within each concept there are significant principles. Some of these are shown in the diagram. Along the periphery of the diagram are some broader generalizations or principles related to the concepts and principles within the circle.

The text consists of a brief statement of each concept. These are followed by expanded, but still very generalized, statements about each of the concepts. Both sets of statements are quite traditional in content and intent. Further details may be found in standard encyclopedias and science textbooks.

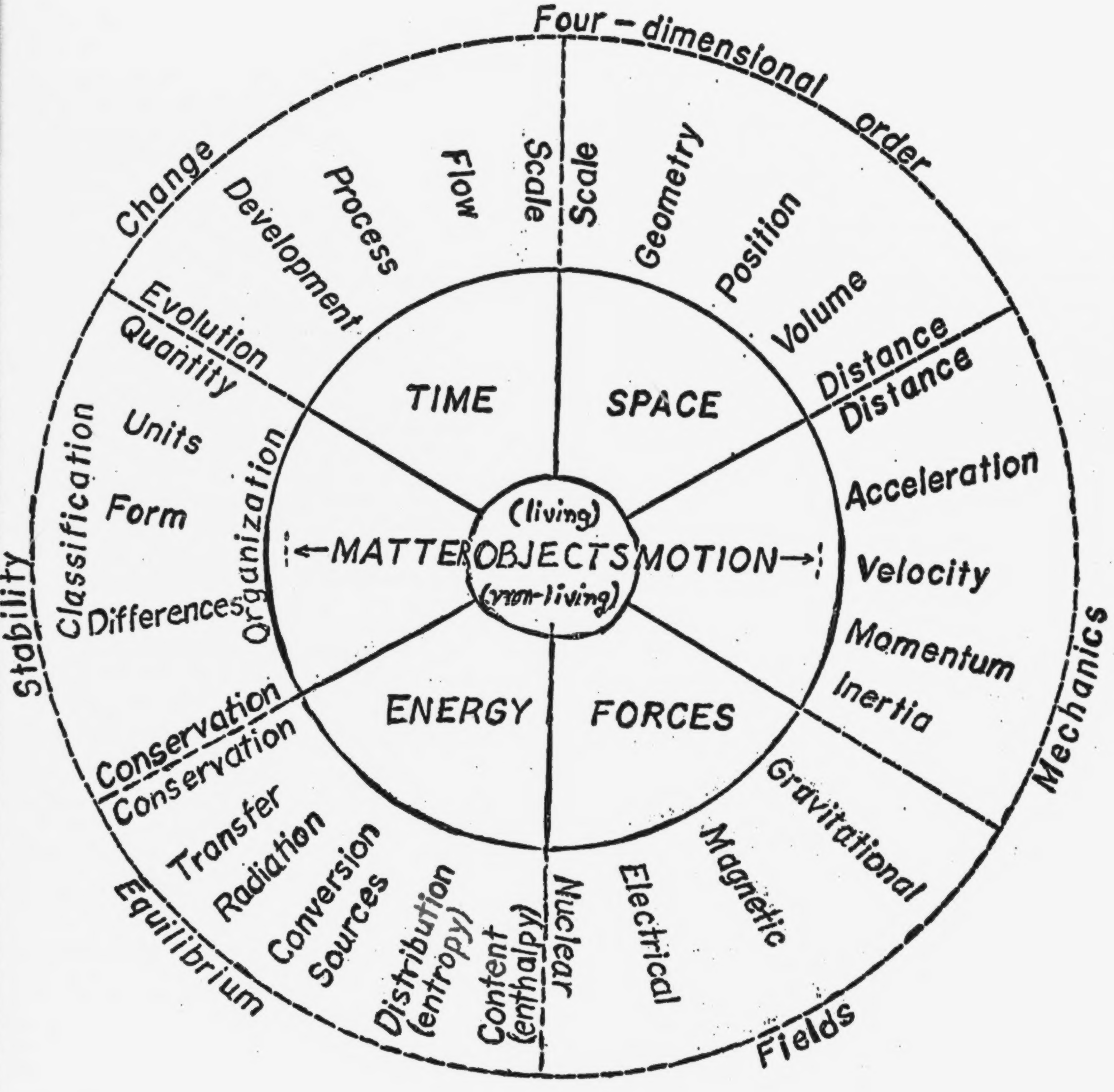
CONCEPTS OF SCIENCE

MATTER: Science is the study of objects. Objects are composed of matter.

ENERGY: Energy is that property of an object or system of matter which enables the body or system to do mechanical work.

FORCES: Force is that impulse which tends to impart motion to an object at rest, or to change the velocity or direction of an object in motion.

MOTION: Motion is that change in position of an object when it is acted upon by a force or forces greater than the force or forces which held the body at rest.

Four - dimensional order
Change
Stability
Equilibrium
Fields
Mechanics
Development
Process
Flow
Scale
Scale
Geometry
Position
Volume
Distance
Distance
Acceleration
Velocity
Momentum
Inertia
Gravitational
Magnetic
Electrical
Nuclear
Content (enthalpy)
Distribution (entropy)
Sources
Conversion
Radiation
Transfer
Conservation
Conservation
Differences
Form
Units
Quantity
Evolution
Classification
Organization
TIME
SPACE
ENERGY
FORCES
←MATTER
OBJECTS
(living)
(non-living)
MOTION→

SPACE: Space is a three (or four) dimensional system of reference which is most convenient for the description of the position of objects, or of the motion of objects.

TIME: Time is a system of reference which is most convenient for describing the sequence and duration of phenomena affecting matter.

MATTER: Matter consists of elementary particles, the most characteristic of which are neutrons, protons, and electrons. The fundamental particles combine in more than 100 characteristic patterns. These patterns are called atoms, which are the smallest elemental particles of matter. Atoms may exist in the free state, combined in molecules, or arranged in continuously repeating geometrical patterns. Free atoms and molecules are characteristic of gases and liquids. Geometrical patterns of atoms (ions) are characteristic of solids and of living matter.

The objects studied by scientists are characterized by distinctive levels of organization of matter. Examples could be: particles--atoms--molecules--cells--tissues--organs--systems of organs--organisms--species--genera--families--orders--classes--phyla--kingdoms; or particles--atoms--minerals--rocks--mountains--continents--planet--solar systems--galaxies--galactic systems--universe. An object at any level of organization includes units of all lower levels and is itself a component within the units of all higher levels.

The scientific classification of objects is essentially descriptive involving only systematic observation and measurement. The scientific analysis and interpretation of objects and of phenomena affecting objects requires consideration of the behavior of matter with respect to energy, forces, motion, space, and time.

ENERGY: Objects contain energy in the form of heat or in forms that may be expressed in terms of heat. Any specific body has a characteristic energy content and energy distribution. Expressions of the energy content include the motions of atoms and particles, changes in atomic combinations and arrangements, and changes of state. Stable objects are systems of matter in which these expressions of the energy content are in equilibrium. If the system gains or loses energy the restoration of equilibrium requires transformations within the system. Such transformations usually result in changes in the characteristic units of matter at one or more levels of organization.

Interactions in nature result in the transformations of energy from one form to another, such as light to heat or potential energy to kinetic energy. In some processes, such as in nuclear reactions, large matter to energy transformations occur. A typical chemical reaction involves changes both in the composition of matter and in chemical potential energy. At the same time, light, heat, electricity, or other forms of energy may either be taken from or given to the surroundings. However, the net gain or loss of matter and energy for the whole universe is invariably zero.

FORCES: The bases of all ordinary interactions between objects are electromagnetic, gravitational, and nuclear forces. Two of these forces, in terms of which all ordinary phenomena must be explained, arise from electromagnetic and gravitational fields. It is possible that a close link exists between these forces; the discovery of this link is the goal of the Unified Field Theory. Nuclear force is invoked to explain the binding of nucleons. However, since one's normal experience is with atoms and aggregates of atoms, the nuclear force need not be considered in most situations.

Chemical bonding in both physical and biological systems involves electomagnetic forces. The motions of falling bodies, planets and satellites are explained in terms of gravitational force.

Though the interaction of all objects in the universe is probably determined by electromagnetic, gravitational, and nuclear forces, the interaction of higher organizational units of living matter cannot, at this time, be interpreted on this basis. It is more fruitful to study the interactions of genetic materials in terms of coded information and energy transformations required to utilize this information in cellular processes. Similarly, the interactions between worms or between human beings can be predicted best in terms of exchange of energy and information between the organisms and between them and their environment.

MOTION: Under ordinary circumstances motion in some form is a universal characteristic of matter. The kinetic theory of matter is one of the most powerful conceptual tools that exists in modern science. The basic assumptions of the theory are quite simple: first, that matter is composed of small, discrete units and, second, that these units are in constant motion.

The states of matter are related to the motions of atomic and molecular units on the basis of kinetic theory. The chief difference among the three states of matter lies in the strength of the forces of attraction and interaction between the discrete units of matter. In solids the units are strongly bonded together, in liquids the bonds are weaker, in gases the units are freemoving with directions and velocity of motion determined by collisions with each other. Temperature is the measure of the average kinetic energy of the units in a sample of matter. As heat energy is added,the motion of the units increases, thereby increasing the average distance between units. However, not all of the energy goes into increasing the translational motion of the units; part goes into vibrational motion and part into rotational motion. These motions of the units of matter play a major role in a wide range of physical and chemical phenomena.

The dynamics of the motions of material objects, whether they be baseballs, automobiles, aircraft, or planets, are expressed in Newton's Laws of Motion. These involve the principles of inertia, acceleration, velocity, and momentum. The motion may be actual with reference to some fixed point, or relative with reference to a point that is itself moving. In either instance motion requires the action and interaction of forces and implies the existence of both space and time.

SPACE and TIME: There would seem to be no concepts more distinctive than space and time. Breakfast in New York, lunch in Los Angeles, and dinner in Honolulu at the usual spacing in time by our watch, can be a real experience. Certainly this seems to be a case of here and there and of now and then. However, in the final analysis, scientific and philosophic considerations of space and time lead to a suggestion that they may be inseparable in reality. Visualizing space as being three dimensional in structure is a human construct which serves as the simplest and most usable basis for purposes of scientific description of phenomena. Time is likewise a construct found to be convenient in the description of natural phenomena. In the theory of relativity the scientific concepts of time and space seem to assume the nature of a single reality. If, in fact, a moving object has a time system of its own, differing from the time system of neighboring objects, moving or stationary, our useful concepts of both space and time are arbitrary constructs for the sake of convenience. However, any concept of motion requires at least workable concepts of both space and time.

Both space and time can conveniently be considered in either a relative or absolute sense. The motions of atoms and molecules in matter, of the baseball from the bat to center field, and of the planets and stars are absolute with reference to three dimensional coordinates. These motions are also relative with respect to the motion of other objects in the same environment. Some events occur before others and are therefore forever older in time than any subsequent event without regard for the actual passage of measured time. Some events have a greater duration than others without reference to the instants of starting and ending.

Science faces the necessity of working effectively with limiting dimensions of space which must become ever smaller on the one hand and larger on the other. The same is true with time. There is a constant search for methods to accurately measure both smaller and larger intervals of time.

EARTH-SPACE SCIENCE IN A CURRICULUM DESIGNED TO DEVELOP THE CONCEPTS OF SCIENCE

Approaches to an understanding of the concepts and principles of science through earth-space science may be appropriate at any grade level of the K-12 sequence. What can be introduced at each grade level, and how it can be introduced most effectively, depends, first of all, on factors peculiar to each school system.

1. The breadth and depth of scientific competence of the curriculum makers.
2. The ability of the curriculum makers to be innovative and imaginative in developing vertical and horizontal integration of student experiences in science with those in mathematics, language arts, and social studies.
3. An understanding of the curricular significance of recent and current developments in learning theory.
4. The competence of the teaching staff at each grade level and in each of the appropriate subject matter areas.
5. The available physical facilities in the school system and in the community. This would include classrooms, laboratories, libraries, audio-visual facilities and access to modern educational media. Facilities in the community of special significance would include

museums, observatories, research laboratories in industry, government agencies, and private or public utilities, teaching and research facilities in institutions of higher learning, and libraries.

6. Most communities will also contain a variety of professional personnel that can be effectively utilized in the development and implementation of the curriculum. These people can be especially valuable in public relations and for in-service programs to improve the competence of teachers.

The utilization of earth science in the curriculum should be undertaken on the basis of two considerations: 1. Earth science is the investigation of the factors which influence our environment. Most communities are economically dependent upon the production, processing, and distribution of natural resources. These resources may be agricultural products, industrial raw materials, or energy. Each of these reflects past or present environmental factors operating in the area. Certainly the health and physical well-being of most communities are related to the maintenance of public sanitation and adequate controls of air and water pollution. Experience has shown that elementary and secondary students will develop enthusiasm for the investigation of familiar aspects of their environment. 2. The earth is, and has always been, a dynamic planet. The air, water, and solid earth which comprise our environment can too easily be taken for granted. The continuous variation in the sensible characteristics of the atmosphere can easily be accepted as evidence that the weather is mainly fortuitous, sometimes capricious, even malevolent. To the average student, water is something that may fall as rain, hail, or snow, flow in muddy turbulence through the lower city, but mostly it is something that comes out of a faucet. Hills and valleys, plains and mountain ranges are seemingly changeless features of the landscape. Earthquakes and volcanoes, for most people, are things that happen elsewhere. There is little about the commonplace factors in our environment to suggest that the weather, rain, and turbulent streams are changing the landscape. At the same time, they are contributing to the substance and location of a mountain range yet unborn. The stars are out there, way out there, but to the casual observer, they seem fixed in relation to us and to each other. Just a little more than casual observation reveals that most stars seem to have a regular movement from east to west across the sky. There are a few which seem to wander, more or less aimlessly, among the others. Ancient observers called these stars the "wanderers" and we call them planets.

The earth is a dynamic planet in a dynamic universe. Everything is subject to change. However, change in nature is neither fortuitous nor isolated in terms of cause and effect. Changes in earth materials are produced by processes which are parts of systems of change. It has been traditional to refer to systems of change in nature as cycles. The two major systems of change of the earth's surface are the hydrologic (water) cycle and the petrogenic (rock) cycle. These are not wholly unrelated as the transformations of earth materials resulting in sedimentary rocks are essential parts of both. The two systems of change depend upon the availability of energy. For the hydrologic cycle, the principal energy source is the sun, whereas the petrogenic cycle depends on energy from sources within the earth.

Within the earth-space sciences there are a number of more or less distinct scientific disciplines. The space sciences are concerned with the dynamics of the universe, present, past, and future. Astrophysics and cosmochemistry extend these areas to extraterrestrial bodies. Selenology is the study of the moon, and is mainly astronomy but includes what is now commonly referred to as the "geology" of the moon. Geology is concerned with the dynamics of the earth, present, past, and future. The major emphasis is upon the dynamics of the solid earth but in many respects this requires significant consideration of the atmosphere and hydrosphere. Meteorology is concerned with the dynamics of the atmosphere, present, past, and future. Climatology, the long-range continuing results of atmospheric dynamics, may be included. Oceanography is concerned with the dynamics of the oceans, present, past, and future. At the interface between the atmosphere and the oceans, oceanography merges with meteorology whereas at the ocean floor it merges with geology. Soil science is concerned with the dynamics of a thin layer of the solid earth just below its interface with the atmosphere. Here the dynamics of living things become a major factor. Geophysics is a broad and varied discipline concerned mainly with the purely physical phenomena of any part of the earth. Geochemistry refers to aspects of a dynamic earth which may be investigated by techniques peculiar to chemistry.

Through the study of earth science the student may be enabled to develop significant understanding of the concepts and principles of science shown in the diagram earlier in this chapter. For present purposes it seems adequate to indicate the conceptually oriented approach to the study of matter. In this instance the study of solid matter as represented by the constituents of the earth's crust.

MATTER

The Constituents of the Earth's Crust

Traditional earth science courses emphasize the classification and identification of minerals and rocks. Commonly this becomes the end product of learning about these materials. Such practice contributes something to knowledge gained but nothing to understanding or concept development.

Actually it is easier and much more rewarding to approach this subject on another basis. What follows is an outline of a method of presentation which maintains an emphasis on principles and concepts. The details are available in modern texts and reference books.

The earth's crust consists of rocks and these in turn are composed of minerals. Minerals, for present purposes, may be defined as the chemical compounds of the earth's crust. Over 98 percent of the earth's crust consists of only eight chemical elements. In order of abundance by weight these are: oxygen, silicon, aluminum, iron,calcium, sodium, potassium, and magnesium. Oxygen comprises almost 47 percent of the crust by weight, but 60 percent of the atoms in the crust are oxygen and this element occupies about 94 percent of the volume of the crust. Silicon comprises 28 percent of the crust by weight, 20 percent of the atoms, but only 0.9 percent of the volume. The facts lead to some interesting conclusions. Atoms of the elements must vary in size and weight. The oxygen atom must be large as well as abundant. The earth's crust can be thought of as a mass of relatively large oxygen atoms with atoms of all the other atoms in the space between the oxygen atoms. Any abundant chemical compounds in the crust can be expected to contain both oxygen and silicon. If the chemical compounds are crystalline solids (having some distinctive geometrical arrangement of atoms), there should be abundant groupings of oxygen and silicon atoms. Observation of the minerals most abundant in the crust (at most 30 in number) confirms this. Furthermore, X-ray analysis of mineral structures reveals that oxygen and silicon atoms almost invariably occur in groups of four oxygen atoms and one silicon atom. The oxygen atoms occur in a pattern permitting them to occupy a minimum of space. This can best be visualized if we assume that atoms occupy a spherical bit of space. Then we can place three spheres in a triangular arrangement of closest spacing. A fourth sphere is then placed on top of the three so that it nestles firmly in the hollow between them. There is an open space in the interior of the three-dimensional arrangement of oxygen atoms. This open space will accommodate a smaller sphere, large enough not to fall out and small enough not to separate the larger spheres. Among the eight most abundant elements there are only two with atoms the right size to just fit in this space. Silicon atoms provide the most perfect fit which creates the most characteristic arrangement of oxygen and silicon atoms in the earth's crust. This four-to-one arrangement is a characteristic structural unit in all of the most abundant minerals in the crust. These minerals are called silicates. There are hundreds of recognized silicates, depending on how one treats minor variations in chemical composition. However, there are only a couple of dozen that occur as characteristic and essential constituents in rocks.

The great variety of silicates is due principally to three factors.

1. The geometrical patterns in which the oxygen-silicon tetrahedra may be arranged.
2. The size and chemical properties of the atoms, and therefore the elements, which can occur in each pattern to create a stable three-dimensional arrangement.
3. The ability of atoms of one element to substitute, in a crystalline structure, for atoms of another element if the atoms are of approximately the same size.

The known geometrical arrangements of the silica tetrahedra in natural silicates reveal a number of conditions which prevail. The tetrahedra may occur alone, without any structural linkage to others. The tetrahedra may be linked together by sharing one oxygen atom. A tetrahedron may share only one oxygen atom with another tetrahedron, never two or three. A tetrahedron may, however, share one, two, three, or all four of its oxygen atoms with one, two, three, or four other tetrahedra respectively. All of these arrangements are known in natural silicates but the variety of linkage patterns is limited to five.

I. Isolated, independent tetrahedra, no sharing.

II. Groups of tetrahedra, pairs, and rings of three, four, and six, sharing one or two.

III. Chains, single chains and double chains, sharing one or two and three.

IV. Sheets, sharing three.

V. Three dimensional networks, sharing four.

Only groups I, III, IV, and V are common among the rock-forming minerals. Group V is much more abundant than all of the others combined.

The silicates in each group are characterized by the presence of atoms of some of the six other abundant elements. In group I iron and magnesium are the most common. Iron, magnesium and calcium are the characteristic elements of group III; a small amount of aluminum is common. The common minerals in group IV are quite variable. In some of these iron or magnesium is characteristic, in others potassium or sodium occurs. Aluminum can be said to be characteristic of the whole group although it is not present in some. In group V there are two important types. The most abundant type consists of a large number of minerals characterized by relatively abundant aluminum plus sodium, potassium, and calcium or some mixture of these. The second type is one mineral which consists entirely of silica tetrahedra in a three dimensional network. As each silicon atom shares each of its four oxygen atoms with four other silicon atoms the atomic ratio of silicon to oxygen is 1:2. In chemical shorthand this is written SiO_2 which might be called an oxide but it is really the most abundant--quartz.

The ability of atoms of one element to proxy for those of another in a crystalline structure accounts for the great variety of silicates if the distinction is based on chemical analysis. The controlling factor in this interchange is the size of the atoms. To effectively interchange, the atoms of the two elements must be approximately the same size. Slight differences in size do not preclude interchange but may distort the geometry of the structure somewhat. Valence is not a controlling factor in the interchange of atoms in a given structural position. However, an interchange involving a valence difference must be balanced by the addition of an atom or atoms to balance the total electrostatic charge. This leads to almost unlimited variation in the chemical composition of natural silicates in each of the five structural groups.

Perhaps the most important proxy relationship involves the substitution of aluminum atoms for silicon atoms. This is especially important in group V, the framework silicates. As aluminum has a valence of three whereas silicon is four, this interchange creates an unbalanced charge. In the framework silicates, aluminum atoms commonly substitute for approximately one-fourth or one-half of the silicon atoms. In the first instance the charge is balanced by appropriately placed sodium or potassium atoms. In the latter instance calcium atoms can be accommodated in the structure and serve to balance the charge.

In the silicates of groups I and III ferrous iron and magnesium interchange more or less completely. Atoms of aluminum may proxy for those of ferric iron.

In the silicates of group IV, aluminum, magnesium, and ferrous iron may proxy for each other. However, substitution of aluminum for silicon atoms in these silicates is quantitatively less than in group V.

The aluminous silicates of group V commonly contain calcium, sodium, or potassium atoms to balance the charge. Sodium and calcium atoms are about the same size and may proxy for each other if the charge distribution is favorable. The potassium atoms are considerably larger than those of any of the other abundant elements except oxygen. Potassium occurs in some of the group V silicates which are similar in most respects to others in which sodium is abundant.

The general chemical variations among the silicate groups can be illustrated by the following table.

Silicate Groups

Percent	I	III	IV	V
SiO_2	1 ⟶	increases	⟶	
Aluminum		increases	⟶	
Sodium	nil	increases	⟶	
Potassium	nil	increases	⟶	
Calcium	- - - - - - - - - - - -	increases	- - - - - - - →	
Iron	⟶	decreases ⟶	1	nil
Magnesium	⟶	decreases ⟶	1	nil

The silicates of groups I and III and some in group IV are characteristically richer in iron and magnesium. These have traditionally been referred to as the ferromagnesian silicates and are usually black or dark colored. The silicates of group V and some in group IV are richer in silica (SiO_2), aluminum, and the alkalies. These are known as the sialic silicates and they are usually light colored.

An understanding of the silicates is essential to an understanding of rocks and their origins. The silicates which form in a given rock depend of course on the bulk chemical composition available. However, the same bulk composition can result in a half dozen different assemblages of silicates. Each of these assemblages is, in fact, a distinctive rock. The various rocks may represent two or all three of the major rock types generally recognized. Nearly all rocks are composed of silicates. As general rule a rock will consist essentially (80 percent or more) of three or fewer silicates. This suggests at least some approach to equilibrium in the system wherein the rock materials were transformed to their present state.

This approach to earth materials is sound science. It uses a minimum of terminology. The student does not need extensive background in chemistry or geology. It is concerned with relationships among the really abundant materials of the earth's crust. It provides a background for more advanced studies of the processes by which rocks are formed. It does not necessarily lead to the classification and identification of minerals and rocks.

The use of earth science in the development of an understanding of the other forms of matter and of the other concepts of science are fully presented in Investigating the Earth, Houghton Mifflin Co., 1967. This text and the accompanying Teacher's Guide will provide most of the assistance required by curriculum makers seeking to develop concepts through the use of examples from earth science.

The Earth Science Curriculum Project has produced an open-ended Reference Series. These are pamphlets providing a wide variety of information to teachers. Nine pamphlets are now published by Prentice-Hall, Inc., Englewood Cliffs, New Jersey 07632. The titles indicate the kinds of information available.

RS-1 Sources of Earth Science Information

RS-2 Selected References for Earth Science Courses

RS-3 Selected Earth Science Films

RS-4 Selected Maps and Earth Science Publications for the States and Provinces of North America

RS-5 Free Materials for Earth Science Teachers

RS-6 Planetariums, Observatories and Earth Science Exhibits

RS-7 Topographic Maps, their Use and Interpretation

RS-8 Data for Water Budget Computation for Selected Cities in North America

RS-9 Selected Guides for Geologic Field Study in Canada and the United States

The American Geological Institute, 1444 N Street, N.W., Washington, D. C. 20005 sponsors many services and programs in education in addition to the Earth Science Curriculum Project. Among its publications are career pamphlets for high school and college students and GEOTIMES, a monthly news magazine of earth sciences. Among other materials of special interest to elementary and secondary teachers is the Geology and Earth Science Sourcebook. This was published in 1962 by Holt, Rinehart, and Winston with a revised edition to be published in 1968. The Institute has also sponsored a series of films produced by Encyclopaedia Britannica Films. These are modern science films designed for upper elementary and junior high school classes. Nine titles have been completed. These are: 1. Rocks That Form on the Earth's Surface,

2. Rocks that Originate Underground, 3. Erosion--Leveling the Land,
4. Evidence for the Ice Age, 5. Why Do We Still Have Mountains?,
6. Waves on Water, 7. The Beach--A River of Sand, 8. What Makes the Wind Blow? What Makes Clouds. AGI and EBF are also cooperating to produce a series of filmstrips on subjects in earth science.

Materials produced by other curriculum projects may be helpful in teaching earth science at all levels.

Numerous monographs produced by the Physical Science Study Committee and published by Doubleday and Company, Garden City, New York are of special interest in the earth sciences. The following should be noted.

S-5 How Old is the Earth, 1959, by Patrick M. Hurley

S-7 Crystals and Crystal Growing, 1960, by Alan Holden and Phylis Singer

S-14 The Universe at Large, 1960, by Hermann Bondi

S-18 Water, The Mirror of Science, 1961, by Kenneth S. Davis and John A. Day

S-19 The Nature of Violent Storms, 1961, by Louis J. Battan

S-21 Shape and Flow, 1961, by Ascher H. Shapiro

S-22 Gravity, 1962, by George Gamow

S-23 Life in the Universe, 1962, by Michael W. Ovenden

S-24 Radar Observes the Weather, 1962, by Louis J. Battan

S-29 Cloud Physics and Cloud Seeding, 1962, by Louis J. Battan

S-31 Knowledge and Wonder, 1963, by Victor F. Weisskopf

S-34 Waves and Beaches, 1964, by Willard Bascom

S-36 Relativity and Common Sense, 1964, by Hermann Bondi

S-46 The Unclean Sky, 1966, by Louis J. Battan

S-47 Weather on the Planets, 1966, by George Ohring

S-49 Watching for the Wind, 1967, by James G. Edinger

S-50 From Raindrops to Volcanoes, 1967, by Duncan C. Blanchard

S-52 The Heart of the Atom, 1967, by Bernard L. Cohen

S-53 Jet Streams, 1967, by Elmar R. Reiter

S-55 The Edge of Space, 1968, by Richard A. Craig

The Secondary School Science Project, Green Hall, Princeton University, Princeton, New Jersey has produced a program for secondary grades, centered on geology. The materials under the title Space, Time, and Matter have been published by McGraw-Hill Co., New York. Principal items in the materials are student investigation booklets, reading series, laboratory kits, and teacher's aids.

Astronomy for elementary and junior high grades is the objective of the Elementary School Science Project, University of Illinois, Urbana, Illinois. Several single-concept pamphlets and accompanying teacher's guides have been prepared. Additional information can be obtained by writing the project office.

The American Meteorological Society, 125 Beacon Street, Boston, Massachusetts, has produced some excellent films and pamphlets suitable for use in elementary and secondary schools. The preparation of materials continues, for up-to-date information an inquiry should be addressed to the Society.

In addition to the specific references given above interested curriculum planners should investigate all of the many curriculum materials projects in the sciences. Some of these are local or regional in emphasis and have developed materials incorporating aspects of all the environmental sciences. A central source of information is the Report of the International Clearinghouse on Science and Mathematics Curricular Developments. Inquiries may be addressed to the Clearinghouse, Science Teaching Center, University of Maryland, College Park 20742.

CHAPTER VII

CONCEPTUAL ORGANIZATION OF PHYSICS

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Of all the natural sciences, it is probably most easy to find a strong conceptual organization in physics, for the reason that this discipline deals with nature at its most fundamental level. Conceptual schemes develop when man reaches the limit of his capacity to account for observed phenomena in terms of other observations or experiences. It is at this point that he invents conceptual models to account for his observations, models which are not susceptible to direct experimental confirmation, but which nevertheless provide the scientific community with intellectually satisfying explanations; articles of faith, so to speak. Since physics is generally regarded as the most basic of the natural sciences, it is not surprising that the role of conceptual schemes in science is perhaps most evident here.

Each of the broad conceptual ideas listed in Chapter II as major conceptual schemes of science has obvious applications in the field of physics. Several, in fact, owe their origin to this field. Taken together, these statements provide a convenient outline of the central areas of thought in contemporary physics. This is perhaps best illustrated by way of a few examples.

Particles and Structure

We mentioned above that physics is the most basic of all the natural sciences; it is also the broadest. It deals with the longest structural formations in the universe (stars, galaxies, etc.) and with the smallest subnuclear units or particles. Modern physics is essentially the physics of fundamental, sometimes called "elementary," particles. The underlying thought, or conceptual scheme, is that all matter is composed of various kinds of particles -- electrons, nucleons (protons, neutrons), atoms, molecules -- and that the differences in matter lie chiefly in the kind and management of these particles that go to make up a given sample. It is also tempting to believe that all natural phenomena ultimately must be described in terms of interactions among these particles. The particles are pictured as interacting through fields of force surrounding each one, the net behavior of the overall object being the sum of the small individual effects due to its particles. For example, the gravitational attraction between two objects would be viewed as the summation of the forces between the particles of these objects.

The type of particle that one must consider in any given case depends upon the energy available for the particular process. In this sense molecular physics is at the lowest end of the scale. It deals with the interaction of atoms to form molecules and the nature of the forces that bind the atoms. The energies involved are rather small, on the order of several electron-volts per atom. This is the energy region of most chemical reactions. In fact, practically all our everyday experience with matter, including living things, is at this energy level.

The next level of organization involves energies ranging from roughly ten electron volts, to tens of thousands of electron volts. This is the region of atomic physics, and the energies specified are the binding energies of the electrons in the atoms. In order to explore the structure of atoms, or to remove their electrons, energies of this magnitude are required. The reasons for the wide range of energies, of course, are that the heavier atoms have more electrons and higher nuclear charge; hence their binding energies are correspondingly greater. Our current picture of the atom is based upon the Bohr theory, which is probably one of the best examples we have of the role of conceptual models in physics.

Beyond the level of atomic physics, in the energy range of several million electron volts, is the region of nuclear physics. The structure of the nucleus begins to unfold only when probed with energies of this magnitude, i.e., the binding energies of nucleons (neutrons and protons). Similarly, most nuclear processes, such as fission, fusion, and radioactivity, involve energy changes of this sort.

The final level in this energy hierarchy is that of high-energy or elementary particle physics. Here, with energies in the billion electron-volt range, one probes nucleons to determine their subnuclear structures and to seek the ultimate particles in nature, if indeed there are such things. As one probes deeper and deeper, higher and higher energies are required, with the end not yet in sight. This is obviously the study of matter at its most fundamental level.

The Quantum Theory of Radiation

Underlying all of modern physics, and closely related to the particle view of matter, is the quantum theory of radiation. Introduced by Planck at the turn of the century, and since "verified" by innumerable examples, it has strongly influenced all contemporary science, setting it off on new and fruitful paths. Contrary to classical ideas, the quantum theory asserts that energy can be emitted or absorbed by a system only in discrete units or quanta. Thus energy, that is, electromagnetic radiation, is now viewed as having "corpuscular" or particle properties, at least as far as its interaction with matter is concerned.

Interactions

Of all the branches of physics probably the most basic are mechanics and field theory. The former deals with the motion of objects (particles) under the action of various forces, while field theory is concerned with the properties of these forces; that is, with the nature, origin, and other pertinent characteristics of fields of force. Together, these two brances include all physical phenomena. One might say, in fact, that the present goal of physics is to understand all natural phenomena in terms of particles and fields.

We know of only two "fundamental" particles having a permanent existence in the free state -- protons and electrons. All others, including the neutron, are unstable as free particles, although within the nucleus it appears that the neutron is stable. At least in stable (non-radioactive) nuclei it is clear that the average number of neutrons in a given nucleus remains constant.

The photon, which is the "particle" (in the Planck sense) of the electromagnetic field, also has a transitory existence. Photons have no rest mass, which simply means that they are created, exist only while in motion, and then disappear by absorption in matter or by producing particle-anti-particle pairs.

In a sense it is almost a matter of definition as to what is a "fundamental" particle -- or, for that matter, what constitutes a particle. None of the particles, including the proton and electron, are the ideal, "hard-sphere," structureless objects envisioned by the early proponents of the atomic theory of matter. Instead, as we probe these particles, we find that they exhibit structure, including still other particles. Moreover, according to a fundamental principle of quantum mechanics, the things we normally think of as particles sometimes manifest themselves as fields or waves, depending upon the experimental conditions. This, coupled with Planck's quantum or "particle" view of radiation, gives rise to the so-called "wave-particle duality," which has deep philosophical implications as well as a major role in the conceptual structure of physics.

The interaction of particles with one another takes place through fields of force, of which we can distinguish only three (or four) basic types (depending upon how one classifies them). The two familiar types of force are gravity and electromagnetism, and most phenomena with which we have daily contact must be accounted for in terms of these. In fact, the electric force is sufficient to account for almost all our experiences, including virtually all of biology and chemistry. These are simply the atomic and molecular phenomena described earlier.

The third major force is that responsible for nuclear phenomena, and this may be further subdivided into two categories; strong nuclear forces and "weak" interactions. A major difference between nuclear forces on the one hand, and gravitational and electromagnetic forces on the other, lies in the range over which these forces operate. Gravitational and electromagnetic forces are essentially long-range forces, falling off as the square of the distance separating the particles involved. After all, the gravitational force accounts for keeping the planets in their orbits about the sun, as well as keeping us on the surface of the earth. So the force obviously operates over great distances. On the other hand, nuclear forces are effective only over distances comparable to nuclear dimensions, falling off very strongly with increasing distance.

The strong nuclear force is independent of electric charge and appears to be the same between any pair of nucleons; i.e., between pairs of protons, or between pairs of neutrons, or between proton and neutron. What is more, such interactions take place in extremely short times, on the order of 10^{-23} second. The weak interaction, on the other hand, requires much longer times, roughly 10^{-10} second or longer, and is believed to be responsible for most nuclear decay processes. It is primarily this large difference in interaction times that distinguishes these two types of nuclear force. Neither one is yet clearly understood, but the difference between them is unmistakable.

Change (and the Conservation Laws)

We know that taken as a whole the universe is constantly changing. This is evident not only for the universe but also for most of its subunits; stars, planets, living things, objects that wear out with use, etc. Few things seem to remain the same forever. Perhaps an exception are the basic building blocks of matter, i.e., atoms. We know that most atoms are remarkably stable, so much so, in fact, that the carbon atoms in this page must have existed in their present form (although not in their present molecular structure) at least since the earth was formed. While most atoms may remain the same structurally (not radioactive atoms, of course), they, too, change in a way: they are constantly moving about and interacting with other particles.

One of the most powerful conceptual ideas in physics relative to a changing universe, is that while the matter in the universe may change, either in structure or in state of motion, there are some properties of matter that never change. These invariant properties are said to be "conserved," and statements describing them are known as the "conservation laws."

The most fundamental of the conservation laws are conservation of electric charge and conservation of energy. Two others, conservation of matter and conservation of momentum, must be viewed in a somewhat different framework. Other, more esoteric conservation rules, involving certain symmetry or space properties of systems, will not be considered here. Nor will conservation of certain types of particles.

Conservation of Matter

Conservation of matter can be considered in two ways, one being conservation of mass and the other being conservation of number of particles (atoms, molecules, etc.). In chemical reactions, for all practical purposes, both mass and number of atoms appear to be conserved; the number of molecules, of course, does not necessarily remain the same. It is, of course, true that atoms or rather, nuclei, are conserved in chemical reactions. But mass appears to be conserved only because the change in mass during a typical reaction is so small as to be beyond the limit of detection. Nevertheless, according to Einstein's Special Theory of Relativity, mass is related to energy, in a very simple manner ($\Delta E = \Delta m \cdot C^2$) so that if the energy of a system changes by an amount ΔE, as in a chemical reaction, its mass must change by Δm.

In chemical reactions the energy change (per atom) is too small to cause a noticeable mass difference. Only in nuclear reactions is the energy great enough to produce appreciable mass changes, so that in physics we cannot speak of conservation of mass unless we consider energy and mass to be equivalent and interchangeable. In a similar sense, conservation of atoms, or of particles generally, does not hold in nuclear reactions. Nor are nucleons (neutrons and protons) always conserved in nuclear processes, although their total number does remain the same for all reactions not involving anti-particles. That is, unless a proton or neutron collides with an anti-proton or anti-neutron, which may result in the mutual annihilation of the particle and its anti-particle, the total number of nucleons would be conserved.

Thus one can see that unlike chemistry (or the life sciences), conservation of matter is not a meaningful concept in physics.

Conservation of Momentum

Momentum, which is a dynamical quantity, was called by Newton the "quantity of motion" of a system. Linear momentum is the product of the mass and the velocity of an object. As a consequence of Newton's laws of motion it is a simple matter to show that in any interaction among the particles of a system, assuming no external forces act on it, the total linear momentum of that system remains constant. If the entire universe is considered as the "system," it follows, since there can be no external forces acting on it, that the total linear momentum of the universe is conserved.

Once we have shown that the linear momentum of a system is conserved, it is easy to prove that its angular momentum also remains unchanged. This quantity is the product of its angular velocity and moment of inertia, the latter involving both the mass of the rotating system and the distribution of that mass about the axis of rotation.

One can find many examples of momentum conservation: the recoil of a rifle, the action of a jet engine or rocket, billiard ball collisions, collisions of atoms and nuclear particles, the behavior of gyroscopes, the way in which figure skaters control their spins by varying the position of their arms relative to the body (which changes their moment of inertia), etc. And on a cosmic scale, the rotation and spin of the planets, the motions of stars and galaxies -- all appear to be governed by this conservation principle.

Bear in mind that this principle derives from Newton's laws, which suggests that in a sense its validity depends upon acceptance of these laws. But whatever its origin, whether stemming directly from man's imagination or derived from another synthesis of ideas such as Newton's laws, the power of a conceptual scheme lies in its ability to withstand repeated challenge and in its range of applicability. The particular value of this conservation law in physics is that it makes possible the solution of certain problems involving interactions without detailed knowledge of the forces involved.

Conservation of Charge

Electric charge is one of the fundamental properties of matter. If we examine those processes involving charge interactions, including the creation (pair production) and annihilation of charged particles, we are led to conclude that the total electric charge in the universe is a constant. Ordinarily, our observations of electrical phenomena on a "large scale" (e.g., batteries, electric circuits, etc.) would not convince us of this because we tend to confuse conservation of charge with conservation of electric current, and the latter, of course, requires a continual energy supply. However, on the particle level (molecules, atoms, etc.) it is easy to see that charge is conserved.

For example, in chemical reactions, such as the formation of a molecule from two or more atoms, the net charge on the molecule remains the same as the sum of the charges on the atoms--namely zero. That is, the total number of electrons still equals the total number of protons in the molecule. Or, if an atom or molecule becomes ionized by losing an electron the net charge of the system (ion plus electron) does not change. Since all electrons carry exactly the same negative charge, and this is precisely equal (within the limits of our measurements) to the positive charge on every proton, all that we effect on the chemical level is a separation or rearrangement of charge. We cannot create or destroy it.

At the nuclear level we can see the apparent creation and destruction of charge, yet upon close examination it seems clear that the total charge is conserved. For example, free neutrons undergo spontaneous decay into proton-electron pairs; the net charge in such a process remains the same, namely zero, although it would appear that the total charge in the universe has been increased by two units. Similarly, in pair production, the process in which a high energy photon (unchanged) forms an electron-positron pair, it appears as though the total charge increases although the net charge remains unchanged. However, the ultimate fate of every positron is annihilation by an electron to form photons. Consideration of such "inverse" processes leads one to conclude that not only is electric charge conserved in any given reaction, but on the average the total charge (positive plus negative) in the universe remains constant and the net charge is zero.

Conservation of Energy

Probably the most significant of all the conservation laws is conservation of energy. Not only is it one of the basic laws of physics but a cornerstone for all natural science, the life sciences as well as the physical. In fact, it was primarily from observations in biology that Mayer, a physician, first formulated the principle of energy conservation a little more than a century ago.

An interesting feature of this conservation law is that it deals with an abstract concept, energy, for which we have no precise description except to say that what we mean by the energy of a system is its capacity for doing work, and which we determine by calculating the amount of physical work the system is capable of doing. Yet despite the fact that the idea of energy itself is so abstract, we nevertheless believe that the total energy in the universe remains constant, and that in any given process energy is conserved in one form or another.

If one considers mechanical energy alone it is not easy to be convinced of this conservation law. For example, a bouncing ball never returns to the height from which it is dropped. Machines do not operate at 100 percent efficiency. Even a pendulum, which is perhaps the closest one can come to a "perfect" machine for interchanging potential and kinetic energy, eventually comes to rest, dissipating its total energy in the form of heat.

Thus it is only when heat is also considered a form of energy that the conservation idea becomes plausible. It is interesting to note that while one can easily convert mechanical energy completely into heat, which is after all a measure of the mechanical energy of the atoms or molecules of a system, the converse is impossible in a practical sense. We cannot transform thermal energy to mechanical work with anything approaching full efficiency. Hence, if the total energy in the universe is constant, it follows that the amount available to us for useful work is continually decreasing, which is the same as saying that the entropy of "disorder" in the universe is increasing. The so-called "laws of thermodynamics" govern the energy available for doing work in any given system.

Another modification must be made if this conservation law is to have wide application. We have seen that according to the Special Theory of Relativity, mass may be converted to energy under certain conditions, and, conversely, whenever the energy of a system changes, its mass must change accordingly. While in most ordinary cases these changes are negligibly small, there are many, including the nuclear processes constantly going on in the universe, in which they are significant.

Hence, a complete statement of energy conservation must also include mass as a form of energy. It is for this reason that the law is sometimes referred to as the "law of conservation of mass-energy."

Random Motion and Probability

The modern view of nature is essentially a statistical view. This implies that the so-called "laws of nature" are in reality laws of large numbers. This is certainly true of physical laws. On the microphysical level the behavior of matter appears governed by random chance, as is shown so well by the irregularity of radioactive decay or by the random motion of small particles suspended in a gas or liquid (Brownian motion). Consider a gas, for example, and the simple empirical relation known as Boyle's law; then imagine trying to verify this law for a very small sample of the gas, so small that it contains only a few molecules. It should be evident that under these conditions Boyle's law could not be verified. In fact, the concepts of pressure and temperature would have little experimental meaning. And if one could measure the pressure at a given time, a subsequent measurement would not necessarily yield the same result. All that one could determine would be very crude average values of pressure. The greater the number of molecules in the sample the more accurately are these averages determined until, with the sort of samples one normally has experience with, the fluctuations in pressure seem to disappear completely, to be replaced by certainty and predictability.

Most of our experience with nature involves large numbers. Hence on the whole, nature appears regular and predictable. When we "drop" an object we expect it to fall to earth. We can even predict the time required for it to fall from a given height. Yet if we take smaller and smaller objects, so small that the motion of gas molecules in the surrounding air influences the motion of these objects (through the Brownian effect), we can no longer accurately predict the time of fall. In fact, the object (say a particle of dust or smoke) might rise instead of fall.

The same is true of all natural events. As in games of chance we cannot predict individual behavior, but given large enough samples we can predict the overall average behavior. Most samples of matter with which one normally deals contain enormous numbers of atoms or molecules -- on the order of 10^{20} or more. It is therefore not surprising that we see regularity rather than randomness. Yet there are situations, particularly in nuclear physics, where random behavior is so very evident. One such example is radioactive decay. We know it is impossible to predict when a given radioactive atom in a sample will decay. And when we observe the decay of a typical (weak) sample the fluctuations in decay rate are quite apparent. But we can, by applying the so-called "mathematical laws of probability" to the problem, accurately predict how long it will take for a given fraction of the sample to decay. We thus know the half-lives of very long-lived radioactive materials by applying such mathematical methods to limited experimental data.

Much of nuclear physics falls into this category; the number of events observed in a typical experiment is so small as to require statistical analysis in order to infer average behavior of the system.

Perhaps nowhere is the idea of randomness so effectively demonstrated as in the kinetic theory of gases. In this conceptual model of a gas one assumes that it is made up of large numbers of particles (atoms or molecules) which are in rapid, random motion. From this assumption one deduces by statistical means the average behavior of the system of particles, including the concepts of pressure, temperature, and heat content of the sample; all these properties derive from the assumed motion of the particles. Moreover the general gas law, previously empirically derived, is now given a firm theoretical foundation. Thus the kinetic theory of gases, which is one of the major conceptual schemes of physics (and of science generally), has at its roots both the assumption of discrete particles and their random motion.

The diffusion of gases or liquids is also accounted for in terms of kinetic theory. Here again, while we can say nothing about the individual behavior of molecules we can make accurate statements about their collective behavior, including the calculation of diffusion rates.

On the cosmic scale randomness is also apparent. There is no discernible pattern in the distribution of stars or galaxies, nor can one predict when a given star will explode as a supernova or another star be born from the gaseous debris in the universe. Yet despite its vastness we seek to infer the average properties of the universe from observations made on a minute fraction of it.

APPENDIX

APPENDIX A

THE NATURE OF THE PROBLEM

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INTRODUCTION -- The curriculum reform movement in science teaching has been active for more than a decade. Some of the major problems, such as the value of laboratory work and the logical organization of courses, appear to have evoked common agreement.

Science curriculum developments are influenced by changes in society, new developments in the sciences, new concepts in educational theory, and the interaction of these components. This means that the curriculum specialists in science should be familiar with the major ideas found in a wide range of fields: anthropology, economics, sociology, psychology, public policy, and manpower, as well as the current status of various sciences. They need to be aware of social and cultural changes, the place of science in society, and the relevance of each for the teaching of science.

To educate a citizenry that will be knowledgeable about the scientific enterprise and its place in the intellectual and social life of modern America requires provision for the study of science for more than just a year in the elementary and secondary schools. Curriculum improvement in science should be viewed as a project extending from kindergarten through grade 12 and into the college years. However, it is reasonable to expect that scientific literacy may be achieved by means of a carefully planned science program.

To begin a curriculum reform without first establishing at least a tentative basis for decisions is wasteful of time and effort and seldom produces significant improvements. Another major issue in science education in American schools has been the lack of a workable science teaching strategy and a lack of clarity concerning major goals of instruction that could serve as a basis for making curriculum decisions. The value of a stated educational strategy is that it may free the teacher and the researcher from the constraints of tradition, make the development of new ideas more likely, and give perspective to curriculum and instructional issues.

Local action groups can make the best use of this document by first comparing it, issue by issue, with their own views on science teaching, noting what they can or cannot accept. Second, they should prepare a clear-cut formulation of acceptable purposes for an education in science, for which this document provides one point of view for debate. It is expected that working groups may wish to adapt their viewpoints relative to local needs and to modify their beliefs frequently as progress is made on the curriculum design and as communication between members of the working committees becomes clearer. The nationwide curriculum studies at the elementary, junior and senior high school levels provide points of view on the teaching of science that are worthy of study. In these studies one will find beliefs and curriculum models that are frequently in contrast to usual practices.

Several assumptions underlie the ideas expressed in most studies: (1) The program of education for an age of science is in need of serious reevaluation; (2) the resulting curriculum should be consistent with the modes of inquiry and conceptual basis of the sciences; and (3) the interaction of science, technology, and society is basic to understanding the modern world.

SCIENCE TEACHING AND CULTURAL CHANGE -- A rapidly changing society stimulated by advances in science and technology requires an educational program designed to meet the challenge of change and assure progress.

Schools exist to help young people know, interpret and participate in the life of their time. When cultural change and progress were slow, instruction in science could lag fifty years or more with little observable consequence for the individual or the nation. At the turn of this century, however, America began its development from an agrarian society to a scientific-technological-industrialized society. Revisions in science curricula typically reflected new technological achievements rather than new thinking in science. The impact of science and technology on social conditions, on economic development, on political action, and on world affairs escaped widespread attention, even among highly educated nonscientists. In many ways the influence of science and technology in shaping modern America is part of the unwritten history of the Twentieth Century.

By mid-Century it was quite evident that America had evolved from an agrarian to a scientific-technological society, from rural to metropolitan communities, and that in many ways our pattern of life and philosophic values were changing. Science has become an integral part of American life. The demand for scientific and technical manpower more than doubled in a decade. The demand will be even greater in years to come. But the science curriculum remained static, largely oriented to a period that no longer exists, and based on content of sometimes doubtful scientific significance.

POINT OF VIEW -- Education in science should be based upon concepts and basic laws, and upon processes of inquiry that facilitate the use of knowledge in meeting new demands.

American elementary and secondary schools need a science curriculum that makes it possible for young people to meet the challenges of a changing society through rational means. Because our culture is characterized by progress and rapid change, an education in science must develop the intellectual talents and attitudes essential to an individual's future welfare and to the sustained progress of mankind. We need to recognize that progress is determined not so much by tools and material resources as it is by extending intellectual capabilities, humane qualities, and the appreciation of scientific endeavors. This suggests an education in science that is oriented to lifelong learning, rational and independent thinking, and an appreciation of the intellectual and esthetic benefits of science. Life is longer than school and the education of youth must prepare him for times he has yet to live through, discoveries not yet made and social uncertainties yet to be resolved. This is a new world in which tomorrow will not be like today; the very nature of science and technology provides assurance that this will be true. Our need is for an education to cope with change, to appreciate the potentialities of change, and to assume responsibility for the direction of change. In short, man needs to insure that he will be served by change rather than become its victim.

The influence of science and technology on national policy, on the intellectual thought of our times, on economic, social and political problems, and on our everyday activities illustrates that science is pervading the whole of life. In the modern world everyone needs an understanding of science, or he is likely to be blindly buffeted by the forces that give direction and meaning to modern living. Without some grasp of science today a person is likely to become a foreigner within his own culture. But it is not enough for science teachers simply to convey their subject as a technical one; they must exhibit it as essentially humane. Science teaching provides liberal education only in humanistic and social contexts.

GOALS OF SCIENCE TEACHING -- Science teaching should result in scientifically literate citizens.

Goals represent a conception of educational values that we believe are important in science teaching. They must describe how the ideal American citizen, educated in science, should behave. Our conception of the ideal is now in the process of change. The new age of science and technology has brought about a modern world to which traditional patterns of education are unsuitable. We have new aspirations, new values, and new modes of inquiry. The scope of educational responsibility placed upon schools has increased and an understanding of science has become more important to mankind. In schools we encounter diverse kinds of curricula directed toward new ends, and we find innovative suggestions for relating curriculum to instructional practices. The ultimate aim of these innovations in curricula and in instructional practices is the achievement of the new goals of science teaching.

POINT OF VIEW -- To state the goals of science education is to describe the intellectual skills, the affective behaviors, the conceptual knowledge and the humanistic qualities that describe the person we are seeking to develop.

A statement of goals for an education in science should describe what we mean by a scientifically literate person living in modern times. This person is the end product, as we see him, of ten to fifteen years of science education beginning with kindergarten. At every level of his education the goals for science teaching are the same because they are derived from common disciplines and from the educational demands of contemporary society.

For instructional purposes general goals need to be broken into small components that can be attained one after another. Conceptual patterns are formed from smaller units, concepts and principles, and in turn each of these relates to and builds upon previous levels of understanding. Planning from one educational level to the next must be done with recognition of the developmental status of the learner and the need for a systematic introduction of relevant concepts at increasingly higher levels of organization. The general goal of producing independent inquirers might be achieved by first discovering what supporting skills should be learned and in what order. Our expectation is that a person literate in science will understand a wide variety of ways in which the concepts of science can be shared with others. Some of these ways can be learned in elementary school; more sophisticated methods can be science objectives in junior and senior high school courses. Communication is a goal throughout the total science curriculum; it is one aspect of inquiry. By examining other goals in appropriate fashions and separating them into small enough components, we can identify supporting instructional materials, teaching methods, and evaluative procedures.

We do not seek here to prescribe the specific materials, methods, or procedures. Nor do we wish to limit the goals to our own definitions because they may be expanded and revised by local groups and over a period of time. We do suggest the goal of producing a scientifically literate person by means of a general education in science, and we list here some of the characteristics of that person.

- He has faith in the logical processes of science and uses its modes of inquiry, but at the same time recognizes their limitations and the situations for which they are peculiarly appropriate.

- He enjoys science for the intellectual stimulus it provides, for the beauty of its explanations, the pleasure that comes from knowing, and the excitement stemming from discovery.

- He has more than a common sense understanding of the natural world.

- He appreciates the interaction of science and technology, recognizing that each reflects as well as stimulates the course of social and economic development, but he is aware that science and technology do not progress at equal rates.

- He is able to derive conclusions from some of the major concepts, laws, and theories of science.

-- He understands that science is one but not the only way of viewing natural phenomena and that even among the sciences there are rival points of view.

-- He appreciates that knowledge is generated by people with a compelling desire to understand the natural world.

-- He recognizes that knowledge in science grows, possibly without limit, and that the knowledge of one generation "engulfs, upsets, and complements all knowledge of the natural world before."

-- He appreciates the essential lag between frontier research and the popular understanding of new achievements and the importance of narrowing this gap,

-- He recognizes that the achievements of science and technology can be basic to the advancement of human welfare, provided diligence is continuously exercised to direct science toward constructive rather than destructive processes.

-- He recognizes that the meaning of science depends as much on its inquiry process as on its conceptual patterns and theories.

-- He understands the role of the scientific enterprise in society and appreciates the cultural conditions under which it thrives.

-- He recognizes universality of science; it has no national, cultural, or ethnic boundaries.

These goals suggest the ends of a liberal education in science but there are undoubtedly other goals of importance; these statements are only suggestive. Education for an age of science must of necessity point in directions different from those of an agrarian society.

LEARNING SCIENCE -- The learning of science is dependent upon an understanding of its conceptual patterns, its modes of scientific inquiry, and upon the developmental status of the learner.

It is difficult at any time to relate theories of learning to practical ends, and particularly difficult if we wish to apply learning theory specifically to instruction in science. The learning of a substantive field is dependent upon the way its knowledge is organized, its processes of inquiry, and the ability and motivational status of the learner. The goals of science teaching suggest the long-term learning outcomes that are desirable and imply the nature of instruction essential to realize these ends. We can assume that some teaching procedures and learning materials are better than others for motivating inquiry and for developing an understanding of science concepts. We can also assume that appropriate instructional procedures for one learner will not be suitable for another, and that motivational factors are seldom the same for all pupils.

POINT OF VIEW -- The educational setting and the choice of instructional materials are closely related to achieving the goals of science teaching.

How effectively children and youth will learn science, in terms of the stated goals, depends upon the proper selection of course content, how it is organized and sequenced, the characteristics and developmental position of the learner, the instructional process, the character of the support materials (for example, textbooks, experiments, films), and the nature of the evaluation program: All these phases of teaching must be in harmony and consistent with each other. A limiting factor in the success of most educational reform movements has been the failure to recognize that curriculum restructuring is more than simply up-dating and reorganizing the course guide, syllabus or textbook. Curriculum improvement has as much to do with teacher and student behavior.

One of the first tasks in teaching science, beginning with the kindergarten, is to encourage the enthusiasm for science which exists in children. Children and youth should have the experience and joy of discovering some things through their own inquiries. As pupils progress through school gaining experience in inquiry they should learn (1) to make selective observations of the natural world and where possible to quantify them; (2) to achieve an organized conception of spatial and temporal relations; (3) to place objects and events in categories or classes; (4) to describe and communicate their observations in objective terms; and (5) to engage in disciplined speculation about the causes of natural events.

The learning of science is best done within a conceptual pattern of knowledge. The forming of concepts depends first of all on understanding the possible relationships of a class of facts, objects or events. Several concepts may be related to each other and these in turn may be organized into a science principle. (This is not automatic.) What is to be learned and the meaning it will have depends in part upon what has been learned previously, how it was acquired, and the use the pupil has been able to make of his learning. Thus, curriculum should proceed at a pace consistent with the pupil's capability of assimilating and integrating new material into already existing conceptual patterns, resulting in new organizations. It is here that we find much of the rationale for developing a coherent science curriculum from kindergarten through grade twelve in terms of unifying principles from science. As the learner acquires something of the conceptual organization of knowledge, he is able to tie past experience with the present and to use both for grasping higher-order relationships and for problem solving.

While the significant facts in science as well as their technological applications change at a bewildering rate, the basic concepts, principles, theories, and conceptual systems are more stable. Since concepts are intellectually more powerful than unorganized information, they provide a better basis for learning and for curriculum organization. There are also basic skills and operations by means of which science is learned and the enterprise of science is understood. Some examples of these skills and operations are: making classifications or cataloguing; forming number relationships, recognizing variables, choosing and making measurements; and recognizing the limitations of each. The learning of science becomes non-science if it is limited to simply the acquisition of information.

To insure in some measure the likelihood that a concept will be formed, the idea must be emphasized specifically. Since we are never quite certain at what phase of development we may find each student in a class, it is necessary that the basic elements of the concept be presented in different contexts and at several levels of abstraction using a variety of instructional media--readings, field studies, films, experiments, and others. In a well-organized course of study, students use concepts formed early in the year to build more complex concepts at a later time, and the concepts formed at one grade level are further developed in the grades that follow. Both the inquiry processes and the conceptual patterns of science must have some degree of a hierarchial organization within the curriculum if students are to experience the most fruitful learning experience.

Words facilitate the development of science concepts, but when improperly taught the results become hollow verbalisms rotely acquired and meaningless. This is one of the dangers of attempting to teach science concepts by learning names and definitions without seeking insight and understanding. Nevertheless, there is an interdependence of concept and language. It is difficult to form a concept without a language rich enough to express it.

How do we help the student to learn the investigatory process that characterizes a researcher and marks the skilled learner? It is wasteful to present facts divorced from a meaningful concept. When facts, which have meaning for the learner, are tied into a logically related conceptual pattern, insight is more likely to occur and retention is improved. After learning one pattern, a student tends to respond more systematically to the alternatives in a new situation. An understanding of conceptual structure and training in inquiry help him select what is pertinent in a new situation. One test of learning is the extent to which a student is able to use concepts or principles and inquiry skills in new contexts and in problem solving.

In any given situation, more than one explanation may seem to apply. There may be no good basis for choosing among alternatives until rather late in the decision-making or problem-solving process. Uncertainties exist during the interval in which the learner actively seeks and processes more data, examines other possible solutions, and finally makes a choice. Pupils need to learn a pattern of delaying responses and of tolerating uncertainty until sufficient data are collected and alternative hypotheses are evaluated.

These procedures imply that the concepts which form the core of a course must be something more than questions for which students seek answers. Problem-solving is only one small part of scientific inquiry. We are seeking to develop a range of inquiry skills which will in turn make it possible for the student to assume responsibility for his own learning and thinking. It is only within this context that one finds promise that the learning of science will be useful for interpreting and explaining the natural world.

SELECTING THE CONTENT OF THE CURRICULUM -- Because science is in a continuous process of change, the content of the science curriculum needs to be constantly re-evaluated, and if necessary, revised to reflect major shifts in thinking and new interpretations of phenomena.

The content of the science curriculum at any grade level should be material which represents some aspect of the conceptual basis of science. The more stable part of scientific thought is found in the basic concepts, principles, and theories and it is these knowledge elements that provide the framework curriculum development. The facts and applications of science are overwhelming in number, tenuous, and limited in their intellectual value when divorced from concepts and principles, and it is for these reasons they are of small value in defining curricula.

Science is characterized by modes of thought and the spirit of inquiry as well as by the discoveries these processes generate. A major reason for teaching science in schools is the many opportunities it provides to develop habits of rational thought in young people. Scientists work on problems in many ways though in most cases the procedure is a disciplined one and not a random activity. In selecting the instructional materials for a curriculum there is need to plan carefully for a wide range of observational and inquiry skills. Since there is always more to a topic that can be successfully taught, the prime consideration in the selection of content should be given to materials that provide good opportunities for gaining experience in the logical processes of science.

Whatever the means for selecting the instructional materials for the science curriculum the developmental characteristics of the learner must be considered. In the range of the curriculum one should also expect to find materials that are suitable for conveying the evolution of ideas in science, science as an activity of people, and science as it relates to technology and to social problems.

POINT OF VIEW -- To develop a comprehensive science program that will achieve the goals of science teaching, the curriculum maker needs to select and organize instructional materials that can be taught to students.

The substantive content for a science curriculum, important concepts and principles, should be chosen by scientists specializing in the branch of science to be taught. The scientist is in the best position to distinguish significant from trivial concepts and to identify those of greatest interpretive and explanatory value. He is also in the best position to recommend a combination of concepts that present a representative "picture" of the area of science that is his special interest.

The research scientist, the philosophers and historians of science, by reason of training and experience, are most qualified to identify the processes of inquiry that are representative of science. These skills cannot with validity be determined by surveys and popular vote of nonscientists.

The specialists in child development and in the psychology of learning, because of their research and study, are in a favorable position to offer suggestions about the learning difficulty of instructional materials and to recommend their approximate location in the curriculum sequence. In designing a science curriculum it is quite evident that initial development of certain concepts needs to come before others and the same is true for the process skills. The psychologists also have the responsibility for identifying the conditions for learning and the methods of instruction that provide a reasonable assurance that the goals of science teaching will be achieved.

The curriculum specialists in science have the responsibility of framing the curriculum by selecting and organizing the content in a way that is supportive of the goals of general education. Since the pre-college science curriculum is designed for all students and its goals are those of liberal education rather than professional training, the final design of the curriculum is best directed by teachers and educational researchers who can place the teaching of science in a social and humane context.

A few of the criteria for the selection of instructional materials for science teaching are: 1. The content must be selected as important by the scholar in the discipline and must be useful in advancing the learner's understanding of science. 2. The content should be representative of the major ideas or concepts of science. The concepts selected should be those with the greatest interpretive and explanatory power. 3. Every field of science has a basis in experimental and investigative processes. To know science is to know also its methods of inquiry. 4. There are connections between sciences and other disciplines. The content for courses needs to be selected to take full advantage of these relationships and to provide wherever possible a logical integration of knowledge. Particular emphasis should be given to the relationship between science and mathematics. 5. Only a small fraction of the basic knowledge of science can be learned during a K-12 program; consequently special attention should be given to including concepts that are most likely to develop an understanding of the intellectual, esthetic, and social contributions of science.

Within the science curriculum there needs to be a range of materials that represents science as a human endeavor to understand the natural world, material that illustrates the cumulative nature of scientific activity, and the evolution of the scientific enterprise. Concepts from many different science disciplines should be included in the curriculum since all science disciplines are not alike. At every grade level there is need for some science instructional materials that are included because they are naturally interesting and fun to learn.

No one of these criteria stands alone, a curriculum has a number of components and its development is much like the weaving of a tapestry: It is the total design that provides the meaningful image.

ORGANIZING THE SCIENCE CURRICULUM FOR LEARNING -- The organization and sequence of instructional materials in a K-12 science curriculum is fundamental to effective learning.

A science curriculum is a systematic organization of instructional materials designed to achieve the purposes of science teaching with maximum effectiveness. The curriculum developer's first task is a consideration of the concepts and inquiry processes he is to work with and of what is involved in learning each. Then the problem becomes one of arranging the materials in both a horizontal (grade level) and vertical (K-12) sequence that assumes a "readiness" for each learning task. The readiness depends upon the mental "set" of the student, rather than the sequence. There is also the problem of developing the supporting materials and some definition of the modes of teaching appropriate to the task and the goals of science teaching.

POINT OF VIEW -- To assure that at every level of learning there will be a readiness for more advanced learning, the curriculum continuum needs to have a hierarchical organization to provide for increasingly complex inquiry skills and a higher degree of concept abstraction.

Since the patterning and integrating of information is essential for the development of knowledge, the conceptual patterns peculiar to the nature of science should be used as a basis for organizing the science curriculum. The materials chosen for instruction should be organized in a manner that requires the learner to continually reorganize, synthesize, and use his knowledge.

A comprehensive curriculum should have a unity resulting from a coherent structure and continuity; it should tell a good story. This suggests that learning should take place in a context which relates present learning to previously acquired knowledge and supplies a foundation for what is to come, this to keep the story a continued one. A good curriculum organization establishes its own continuity by making the steps in learning seem reasonable.

Construction of a science curriculum should not be done in isolation from other parts of the school program. The modes of thought in science, for example, measuring, coding, observing, and inferring, can be useful in other subjects. Skills, rather than information, are likely to be applied to the study of other subject fields. The teaching of science in a cultural and social context provides other meaningful connections between subject fields.

The organizational basis for designing a science curriculum is derived from the nature of science and from the intellectual development of the learner. Conceptual schemes and inquiry processes provide the integrative basis which serves to provide both coherence and continuity to the curriculum. When this framework has been established, it is then possible to select the details of information needed to move the learner toward the established goals.

THE TEACHING OF SCIENCE -- A science curriculum requires modes of teaching compatable with the goals of instruction and with the nature of the discipline.

The success of a new curriculum greatly depends upon how it will be taught and how well. A curriculum reform is as much a matter of improving instruction as it is a reevaluation of course content. The teacher's role in instruction is something more than simply imparting science information. It is in great part one of creating an environment for learning the nature of the scientific enterprise, its concepts and principles, its processes of inquiry, and its place in the affairs of man demands a range of instructional practices that are oriented to each of these goals. Just as there is a plurality of goals that distinguishes the sciences as fields of instruction, there is a plurality of appropriate learning experiences needed to achieve these goals. The success of a new curriculum rests mostly with the teacher's competence and his understanding of the rationale of the program.. However, it is essential to recognize that children and young people learn in all kinds of ways, and to move each pupil toward desired goals is not something that can be routinized, but requires skillfully planned variations in the learning environment and the instructional materials.

POINT OF VIEW -- To encourage independent thinking in science, learning experiences need to be related to the inquiry aspects of science and to the conceptual organization of its knowledge.

A theory of instruction that is particularly suited to the teaching of science is presently the subject of debate and exploratory research. There is much encouragement for viewing curriculum, teaching, and learning as inseparable and interacting attributes of learning. The basis of effective teaching as found has dimensions in: 1. The nature of science: its conceptual organization, and its processes of inquiry and methods of investigation. 2. The nature of the learner: his motives, interests, cognitive skills, developmental level, and intellectual potential. 3. The competence of the teacher: his teaching strategies, ability to communicate, control pattern, philosophical beliefs about education, and understanding of science.

4. The conditions of learning: its processes, contexts, and purposes. 5. The nature of the curriculum: its organization sequence and its conceptual, affective, and procedural phases. 6. The social structure: demands and incentives provided by social and cultural forces.

Instruction links curriculum with teaching goals. While we have recognized instruction as a role of the teacher, we have not fully considered learning as a function of the student, through opportunities to explore, to investigate, to discover and invent ideas with minimum guidance from the teacher. What the pupil does, determines in some measure what the teacher does, for both pupil and teacher are influenced by the teaching and learning environment. There is also an interplay between learning activities, the materials of instruction, and the organization and sequence of the curriculum.

LABORATORY WORK IN SCIENCE TEACHING -- Laboratory and field studies should be designed for the purpose of encouraging students to look at events in a "scientific" way.

The laboratory and field provide a means for relating concepts and principles to the many inquiry procedures of the different sciences. It is here that crude experience is brought into the intellectual framework of science; a place where observations and measurements are made into data through rational thinking and focused on questions. It is at this point that work in the laboratory has its greatest educational value.

Laboratory work and field studies, at whatever grade level, should contain aspects of problem solving, utilizing the student's knowledge of science, and providing experience in scientific inquiry. Experiments solely for the purpose of gathering information, even though the observations are carefully described and summarized, represent only one means for understanding science. Some experiments should be planned for the purpose of providing students a common experience with phenomena, others to provoke argument and discussion. One good way to learn is through discovery activities, where answers are not given or known in advance, and the work of the laboratory and field can provide learning of this kind. The motivational and esthetic values of experiment and field study make these instructional procedures among the most valuable in science teaching.

The inquiry processes of science can be so well presented through laboratory and field studies. The laboratory and field experiences should introduce the learner to the following: 1. The variety, characteristics, and limitations of experimental designs. 2. The relationship between experimental options and the nature of the information obtained. 3. The relationships between observation, experimental results, and the inferences based on the data. 4. The tools of measurement and their influence on experimental accuracy. 5. The use of concepts for generating hypotheses and defining questions and the use of hypotheses to guide data collection. 6. The use of theories and models for interpreting data and for making predictions.

7. The analyzing, ordering, and displaying of data in meaningful ways.
8. The use of mental experiments to explore ideas and test assumptions. We need to recognize that the value of an investigation lies more in the means it provides for exploring the unknown than in verifying the known.

The child's first experiences with science, beginning with primary school, should involve aspects of investigation and discovery. For example, he should learn early in school how to observe with all of his senses, how to measure, classify, use numbers, communicate, and make inferences. Later he should have opportunities to combine these skills and use them to explore his environment to gather and process information that may lead to the formation of concepts and the interpretation of natural events.

Laboratory experiences need to be planned in both horizontal and vertical sequences, thus providing opportunities to use old skills for developing new or more complex skills. Some laboratory experiments form substructures for others. The proper sequencing of experiments makes it possible for the pupil to use concepts and skills acquired earlier to attack increasingly complex problems. A good laboratory program is planned to assist the student in becoming increasingly self-reliant.

CONCLUDING REMARKS -- It would be rash to suggest that all the guidelines for curriculum development in science have been described. There has been an attempt to briefly describe the basic elements of curriculum and to do so with a consistency of viewpoint. The purpose has been to present a logical plan for science teaching that is consistent with the nature of the scientific enterprise.

Not all phases of science teaching have been discussed. There is need for more discussion and research on some of the problems. For other issues, the answers must emerge from one's own rational analysis of the problems. The need for curriculum reform in science teaching is no longer a matter for debate; it is the nature of a desirable curriculum that is not clear. The issues and viewpoints presented here are intended to focus and stimulate local action on existing problems in science education.

APPENDIX B

Planning a Local Action Program for Implementing Curriculum Development in Science

Subcommittee on Local Action Program
of the NSTA Curriculum Committee

Richard W. Schulz, Subcommittee Chairman

(Reprinted from Theory Into Action)

An important function of a professional association is to provide leadership in areas served by the organization. The association should be concerned not only with new ideas that might lead to improvement but also with the implementation of these ideas.

The previous parts of this publication have presented the philosophy and theories of science education of the Association. NSTA has taken a position on curriculum development that hinges on two unifying threads:

1. Science curriculum for our schools must be seen and developed in the total sequence of kindergarten through grade twelve (K-12), or beyond.

2. The conceptual schemes and the process of science should be at the focal point of any science curriculum; they apply to any of the sciences and allow for growth and change in science.

How can we implement these ideas in a way that will be useful to each member of the Association and to each school system or group of educators concerned with science? It is the Association's view that action by those who will be planning and carrying out a particular program is the soundest base for an effective program. Thoughtful consideration and well-planned action will help individuals and school systems become increasingly knowledgeable about today's ferment in science teaching and increasingly perceptive and secure in building a strong science curriculum for the community. Therefore, the following suggestions for planning a local action program are designed to help provide purpose and direction for local self-improvement programs. Elements of such a program include:

-- Interest in improving progression and sequence of science education

-- A forward-looking philosophy of science education

-- Professional and lay personnel willing to devote time to the project

-- A workable plan for carrying out the project

The task of improving a science curriculum is primarily one of selecting and organizing ideas and materials so that they will produce a sequential program, well articulated from step to step throughout the school program. It is in this sense, rather than in that of writing material for a specific course, that the term curriculum development is used in this publication. Progress has already been real and significant within the layers of curriculum at the instructional levels on which attention has been focused. This work should be neither repeated nor ignored, but a relationship must be established among these efforts, gaps must be identified and closed, and fragmentation avoided. These things a local action program can help to accomplish. It can help to bring order to a fluid and sometimes confused situation. It can consider such questions as sequence and content of courses, grade placements, programs for learners of varying levels of ability, different teaching styles, and relations between science and other subject areas, such as mathematics and social science.

ASSUMPTIONS -- The following assumptions by the NSTA are presented as basic to the development of a local action program for implementing a continuing curriculum development in science:

1. The ultimate responsibility, professional and financial, for curriculum development is that of the local school district, yet the curriculum must represent a broad view and avoid localism, whether it be geographic, economic, or social.

2. No single action program can be equally effective for curriculum improvement efforts in all or even a majority of the school districts of the nation. Action programs can be more effective if planned for individual school units.

3. The unique contribution of the NSTA to the organization of science curriculum lies in the area of vertical structure, that is, emphasis on a continuing program from kindergarten through grade 12 and beyond.

4. The curriculum must provide opportunity for the development of scientific literacy for all students.

5. Because of the changing nature and content of science, a science curriculum must look to the future, and curriculum development must be a continuous process.

Because each school district will have its own individual problems and goals, local action programs should be individually tailored to meet the specific needs of that situation. However, there are some components that should appear in almost any local action program. These components are included in the following outline although the sequence may be varied to meet local needs.

ESSENTIAL COMPONENTS FOR A LOCAL ACTION PROGRAM

1. Preplanning session - Determine preliminary strategy, including identification of suggested goals, scope, and estimated costs.

2. Preliminary organization-Appoint steering committee; set tentative goals; determine scope; suggest timetable; develop tentative procedures; prepare budget estimate.

3. Opening conference-Examine recommendations of steering committee; define goals; adopt working procedure.

4. Enlistment of community support.

5. Inservice education.

6. Curriculum development.

7. Implementation and evaluation.

8. Continuing revision and evaluation.

A local action program includes both philosophy and procedures. The NSTA service document, "Toward a Theory of Science Education", and the "Conceptual Schemes and the Process of Science" in the preceding sections of this publication present part of this philosophy. The following guidelines are based on this philosophy and point a way toward effective action in curriculum building.

GUIDELINES FOR THE DEVELOPMENT OF A COORDINATED SCIENCE CURRICULUM THROUGH A LOCAL ACTION PROGRAM

Guideline No. 1: The Local Action Program, at all stages of development, should be coordinated effort, including administrators, teachers, scientists, and competent laymen.

Curriculum development is not a simple process. Development of a superior program will tax the abilities of many members of the entire community. Participants must be carefully chosen, and each must understand his role.

Individuals selected to assist in curriculum development must have:

- An understanding of the objectives of education and a commitment to their implementation
- A sincere interest in improving the educational program for the school or the school system
- Willingness and ability to devote the time necessary to the project
- Sufficient flexibility in thinking to permit the give-and-take essential to the development of a good curriculum.

Following are the groups involved and their responsibilities:

School administrators

- Initiate, encourage, and support curriculum development activities
- Reassign work loads to provide time for committee work and experimental projects
- Arrange financing, coordination, and promotion of the program

Classroom teachers

- Develop, evaluate, and use new curriculum materials experimentally (This requires patience, dedication, and imagination.)

- Recognize that worthwhile progress in curriculum development is a slow and demanding process

Scientists

- Work with teachers to learn the capabilities and limitations of children and youth

- Provide counsel on the accuracy of curriculum materials

- Assist teachers in understanding how scientists think and work

Civic, social, and scientific groups

- Devote time and effort through membership on action committees

- Contribute suggestions for the improvement and development of the curriculum

- Provide continuing moral support

Guideline No. 2: An intensive study of existing research and resource materials should be undertaken to identify worthwhile suggestions for action at all stages of the local action program.

There are many sources of background information and fertile ideas for curriculum development. The bibliography in the Appendix lists some of these sources. Valuable background will also be found in:

- The STEPS program developed by the U.S. Office of Education

- Published curriculum materials, which include those of the Biological Sciences Curriculum Study (BSCS), the Physical Science Study Committee (PSSC), the Chemical Bond Approach project (CBA), and the Chemical Education Material Study (CHEMS)

- Unpublished experimental projects now under way

- Curriculum materials from other local and state curriculum programs

- Community resources of many kinds

Committee members and consultants affiliated with the local action program should be able to add materials that are especially pertinent in the local situation.

A general word of warning may be in order here: The study of resource material is primarily for background information and should not "set" the pattern of thinking so early in the program that good ideas which do not conform to the pattern may be lost.

Guideline No. 3: The curriculum should be developed on at least a K-12 basis. It should be laboratory centered and flexible, yet comprehensive.

The laboratory, as the term is used in science teaching, is the place where observations are made and experiments are conducted. This may be in the school building, outdoors, or in the home. Both scientists and educators have insisted for many years that scientific inquiry and laboratory-centered instruction are essential components of every desirable science program. An important problem facing the planning group will be to arrange for appropriate and adequate laboratory work at every grade level.

Several excellent courses have been developed by groups of scientists and teachers working on a nationwide scale. Excellent as these courses are in themselves, as a group they contain considerable duplication and overlapping. The authors have expressed various points of view, and in many of the courses they have included far more material than can be taught in a single year of study. Before these materials can be used at their maximum effectiveness, it will be necessary to integrate them into a sequential program, selecting for inclusion such of the materials as meet the criteria and needs of the program.

The planners need also to be aware that weaknesses in teacher preparation may be revealed as the curriculum is developed, and they will find it necessary to think beyond grade 12 to consider the effect on college courses of the new and more advanced science courses in high schools and to plan for continuing adult education for laymen.

Guideline No. 4: Curriculum development should be carried out by persons selected for their knowledge of science, their ability in curriculum planning, their facility for critical thinking, and their dedication to the use of inquiry in teaching science.

The lack of imagination and quality in a course of study or in a curriculum may be traced to the lack of these characteristics in the persons responsible for its development. Therefore, it is of the greatest importance that persons with the qualities mentioned in the guideline be brought into the program. If persons lack these qualities, they should be encouraged to develop them. Many districts might profitably spend a year or more in identifying potential leaders and encouraging the development of leadership among teachers before embarking on a program of curriculum development. Administrators should recognize that the identification and selection of personnel is one of the first considerations in planning a local action program.

Teachers with leadership potential can be found in every district. They may not have achieved their greatest potential because of overcrowded classrooms, overloaded schedules, or lack of encouragement from school administrators. A district cannot hope to achieve success in curriculum development until its potential leaders are identified, encouraged to develop their capabilities, and given an opportunity to exercise leadership.

The curriculum must be planned with representation of all of the points of view suggested in the guideline if it is to be sound in content, workable in the administrative framework of the school, and effective in the classroom.

Guideline No. 5: The curriculum should be organized around broad principles in science and should provide opportunity for all students to gain some understanding of the scientific process.

The conceptual schemes and processes presented in this document set forth the broad principles around which a sequential curriculum can be developed. The ultimate goal, of course, is scientific literacy for oncoming generations.

Such conceptual schemes and processes have two outstanding advantages as the backbone of a science curriculum. They can encompass future growth and change in science itself, and they offer a broad outline of science to which the future nonscientist can relate the scientific information that will reach him in his daily life.

The goal of developing scientific literacy and understanding of science on the part of all students is an extremely important part of curriculum development. It will require considerable attention to the needs of the slower student as well as planning for students who will become scientists, professional persons, or leaders in other areas of society. Ample provision for study of educational research on teaching and learning techniques for various ability and interest levels should be included in the plans for the local action program.

Guideline No. 6: The relative importance of science in the curriculum and its relationship to other subjects should be considered at all stages of planning.

Science, mathematics, the language arts, and the social sciences are inextricably related in actual practice. Yet they have been arbitrarily separated in the school curriculum, to the detriment of all. The many relationships that exist need to be explored and strengthened so that students will begin early to see and to utilize the relationships that are becoming increasingly apparent between science and other aspects of life. For example, the historical and social implications of science are extremely important, but have been seriously neglected. An understanding of the social implications of scientific and technological developments is a major factor of scientific literacy, but it can only be developed from habits of thinking that link science with other aspects of life.

Curriculum planners must keep in mind that science is not the only important subject in the curriculum. Planners in each curriculum area share a common responsibility to eliminate unnecessary content and repetition and to develop a program that is both effective and practical.

Guideline No. 7: Teachers should be thoroughly familiar with the principles and practices of scientific inquiry and their use in classroom and laboratory situations.

Experience has shown that many curriculum development programs have been undertaken by teachers who were quite unfamiliar with the philosophy and procedures inherent in scientific inquiry. Since the teacher should be involved in planning the curriculum and will certainly be the person to carry out the curriculum plans, he must be familiar with the goals of the curriculum development program, must be in sympathy with them, and capable of carrying them out.

Most school districts wishing to initiate a local action program of curriculum development would do well to consider the possibility of enlisting selected teachers in an experimental program to demonstrate the effectiveness of introducing scientific inquiry into the classroom and laboratory. Once teachers have experienced the challenge of teaching an inquiry-centered program, the majority of them will become ardent supporters of this method of instruction. Without this conviction and experience, they are not capable of developing and teaching a curriculum that is oriented to the principles and practices of scientific inquiry.

Guideline No. 8: The local action program should include continuing inservice education with adequate provision for discussion among participants as well as for feedback of information to administrators.

A local action program in itself presupposes some changes in course content, philosophy, and methods of teaching. Certainly, increasing attention will be given to the inquiry process of learning as well as to articulation between the grade levels and courses included in the curriculum. It is only realistic, therefore, that plans for an ongoing program of inservice education should be built into the local action program. Such an inservice program will prepare beginning teachers to teach the techniques of scientific inquiry as well as benefit those who will be shifting to this technique. With knowledge expanding so rapidly, there will also be a need for inservice programs to keep teachers up to date with new developments in science.

Guideline No. 9: New materials should be used experimentally before they are incorporated into the curriculum.

Introductory, experimental use of new materials before they are finally accepted for the curriculum provides an opportunity to try a variety of materials and approaches in the situation where they will be used. The most effective can be retained for the new curriculum.

Another very considerable advantage concerns teacher acceptance of new materials. A teacher who is hesitant about, or opposed to, undertaking new procedures and techniques may be bolstered by the idea that the new methods are "experimental" and will be retained only if they are successful. The greatest psychological advantage, however, is that experimental use offers teachers an opportunity to take an active part in the selection of the techniques and procedures that are to be included in the new curriculum.

Guideline No. 10: Evaluation should be planned to begin with the earliest steps in the program and should continue throughout its development.

Evaluation involves much more than the measurement of achievement in the classroom. It should include the appraisal of the effectiveness of each phase of the local action program, as well as teacher and pupil behavior in the classroom. Report sheets, checklists, oral suggestions, and the results of discussion groups should supplement the more formal methods of evaluation commonly used in school systems. Provision for obtaining evaluations of these types, as well as for improving subject-matter testing, should be built into the program. The results of evaluation may indicate a need for changes in plans for inservice education as well as in the curriculum itself.

Guideline No. 11: Curriculum planning is a continuing process. Plans should reflect the need for continuing evaluation and revision. They should not be terminal.

Science, technology, and education are progressing so rapidly that it is essential to provide for continuing revision in the curriculum. It is impossible to predict what science will be like when today's first-grade student graduates from high school. Another factor affecting the adequacy of the curriculum is the continuing change in pupil background and knowledge. As students are introduced to new materials and methods of inquiry, they will need different and more sophisticated approaches in later grades. This in itself will make continuing curriculum revisions mandatory.

Guideline No. 12: A local action program should receive adquate financial, as well as moral, support from the community.

If we accept the premise that the ultimate responsibility for curriculum development lies in the local district, it follows that the responsibility for obtaining adequate financing for the program must lie there as well.

Local groups may look to foundations and other granting agencies for experimental and pilot projects. But even these must provide for continuing financing at the local level if the projects are to continue at the end of a limited period of time. Foundations cannot make grants to all of the thousands of districts that wish to consider problems of curriculum development.

In many areas, the local taxpayer may not be able to bear the entire cost of a curriculum development program. The alternatives, then, are to find volunteer help, curtail the program, or to find outside sources of funds. There are sources that are sometimes neglected in the search for the big grant. For example, some agencies will provide matching funds for science equipment and many other types of curriculum improvement. Local industries and civic agencies will often help support a program if convinced that the project is sound and worth while.

DEVELOPING A LOCAL PLAN OF ACTION - Each community, school system, or group contemplating a local action program for science curriculum development will be in a unique situation and must, in the end, develop its own program pattern. Each group must assess the needs and resources of its community and plan a program of curriculum development that will be flexible, that will provide for revision when needed, and yet offer a definite and workable plan of action.

The NSTA will welcome reports of local action programs and will hope to serve as a clearinghouse of ideas for curriculum development programs. The Association will be glad to encourage and assist in the development of local action programs, within the limitations of its staff and budget. If your district is planning a local action program, the NSTA would like to be informed of your plans and progress. The Association will place you on its mailing list to receive information about further developments in local action programs, if you so request.

APPENDIX C

The NSTA Position Statement

Reprinted from
The Science Teacher
December 1962

The National Science Teachers Association has devoted five years to examination of its beliefs about the science curriculum. Officers, the Board of Directors, Committees, and the members have moved carefully, step by step, toward the formulation of this Position Statement.

In 1958 and in 1959, the Association held special conferences to study selected problems in elementary school science and high school science. These resulted in the two publications: *It's Time for Better Elementary School Science* and *Planning for Excellence in High School Science*. In 1959, also, through sessions at regional meetings and the National Convention at Kansas City, Missouri, the implications of a K-12 curriculum were studied.

During 1960, the NSTA Curriculum Committee prepared a basic outline for the Association's work in reference to curriculum development. This paper, together with suggestions of the Board of Directors and various reviewing groups, was further refined as a guide to Association activities in 1961. During this same year, working papers, including one on curriculum, were prepared for discussion at the 1962 National Convention in San Francisco, California, with the objective of obtaining resolutions for the membership to discuss.

Drawing extensively on this background, the Curriculum Committee developed this Position Statement. It has been approved by the Board of Directors and is published herein so that all who are interested and look to NSTA for guidance may know what the Association's beliefs are on curriculum development in science. The Committee and the Board offer this statement as one that embodies the fundamental concepts of a good science program, reflects the climate of the times, is forward-looking, and can serve as a guide to new and continuing programs in science. In recognition that the importance of this Position Statement lies in its implementation, action programs which will include publications and leadership conferences are being planned.

The Curriculum Committee of NSTA invites all educators to think critically and analytically about this Position Statement. Your opinions regarding the ideas expressed here and your suggestions for implementing them in local school systems will be most welcome. Please direct communications to Marjorie Gardner, Assistant Executive Secretary, NSTA, 1201 Sixteenth Street, N.W., Washington 6, D. C.

DONALD G. DECKER, *Chairman*
NSTA Curriculum Committee

THE NSTA POSITION ON CURRICULUM DEVELOPMENT IN SCIENCE

IN the period since World War II, a number of important changes have occurred in science education. There has been a growing awareness by the general public of the decisive roles played by science and technology in modern society. The climate is conducive to extensive experimentation and change in this area of education. For the most part, changes are occurring in secondary schools and colleges, notably through the revisions of high school science courses on a national scale. In addition, considerable financial support has also been provided to improve laboratory and research facilities in the nation's high schools and colleges.

Several new course improvement programs have been developed, largely with financial aid from the National Science Foundation. The Physical Science Study Committee, the Biological Sciences Curriculum Study, the Chemical Bond Approach Committee, and the Chemical Education Material Study are now well known. A basic premise of each of these groups is that science instruction in most schools is out-of-date and fails to present an understanding of the objectives and methods of scientific inquiry. Programs in the elementary schools and junior high schools manifest the same obsolescence.

In such an atmosphere professional groups and individuals look to their national organizations for guidance. Many school administrators and teachers are willing to explore new curricular and methodological suggestions, but find themselves on the horns of an educational dilemma. On the one hand, there is an honest desire for extensive curriculum changes but, on the other, there is no clear image of the ideal science curriculum. This is particularly true in the elementary and junior high schools, where science is not normally divided into separate disciplines and has, therefore, not been the object of much attention by scientific groups. To develop a one-year course in any one of the separate science disciplines, where for the most part some agreement on content is found among professional scientists, is far easier than to devise an integrated science curriculum that is more than a collection of isolated units selected from the various disciplines. Yet, there is a growing conviction among educators that it is in the elementary grades that the greatest impact can be made in promoting general understanding of the nature of science.

The National Science Teachers Association has a responsibility to be concerned with matters relating to the school science curriculum. The membership has on various occasions affirmed concern in this respect, most recently through (1) the report of the 1962 San Francisco Convention Resolutions Committee and (2) the 1962 report of the Policies Committee. Both urged the Association to assume a leading role in science curriculum development.

The Nature of Science

If NSTA is to further the development of sound science curricula, the Association must clarify the sense in which the term "science" will be used.

Science is the activity through which best explanations are sought for the observed facts of nature. These explanations are expressed as theories or statements which conform to general standards of reliability imposed upon them by the scientific community and which are characterized by economy of thought and expression. In this sense the great conceptual schemes such as the conservation of energy, the kinetic theory of heat, the atomic theory of matter, and the biochemical theory of heredity should be at the focal point of any science curriculum, rather than the individual concepts or the facts about our environment.

There are three aspects of the scientific enterprise. The first consists largely in the observation and description of nature, and is sometimes called *natural history*. It presently comprises the major part of any elementary science curriculum, as well as many high school and introductory college courses in science. In a sense, one might regard this type of knowledge as the first phase of scientific inquiry. It includes not only the more obvious phenomena of our environment but, also, the relationships among these that may be revealed by simple experiments.

The second aspect of the scientific enterprise, *science*, begins with the first —with observation, with descriptive statements, with simple, causal relationships derived from experiment. But it is important in science education to realize that the essence of science lies not so much in seeking out the detailed structure of nature as in trying to understand it. As an example, one might point to Boyle's Law (or the gas laws, generally). This relationship is easily demonstrated; in fact, students may be guided to the "discovery" of this law for themselves. And, as is generally the case in a science curriculum, one can find innumerable practical examples involving the application of Boyle's Law. Instead, what one should look for is the *why* of Boyle's observation—that is, for reasonable explanations. What basic conceptual scheme provides for understanding the behavior of gases? The answer, of course, lies in the kinetic theory of gases. Hence, to speak of the behavior of gases without introducing the kinetic theory in a meaningful fashion marks the difference between a natural history approach and a science approach.

As for the third aspect of the scientific enterprise, *technology*, the distinction between this activity and what we call science is probably more evident than that between natural history and science, where the boundary is not nearly as sharp. While science is an intellectual quest for understanding of natural phenomena, technology is a practical effort to use and control these phenomena. Technology yields the tangible products of science.

All three aspects of the scientific enterprise must be a part of the science curriculum:

1. Descriptive science or natural history, because it provides the basis for scientific inquiry and plays so prominent a role in a child's conventional experience;
2. Science proper, because of its intellectual challenge, which should be a primary goal of scientific education; and
3. Technology, because it serves so well to illustrate the practical application of scientific principles and because of its impact on modern society.

It is clearly impractical to include each of these categories in the same degree at all levels. It is important, however, for students to understand the distinction among these activities which, collectively, make up what is commonly termed "science." Indeed, if little more is accomplished than to clarify in students' minds the nature of the scientific enterprise, a major advance will have been made in science education.

The Role of Mathematics

One cannot speak realistically of a sound science curriculum without considering the important role played by mathematics. Just as science itself could not have developed to its present stage without mathematics, so it is unrealistic to think that the true character of science can be portrayed without mathematical reasoning. Mathematics is the language by which one describes the order in nature and which, in turn, leads to a clearer understanding of that order. Those sciences which rely heavily on mathematical demonstration have been most successful in structuring man's experience. Efforts in science curriculum development should be accompanied by corresponding developments in mathematics, and the two must be closely correlated at all levels.

The Goals of Science Education

Various objectives have been cited in the past as constituting the goals of science education. For the most part, these objectives relate to some utilitarian purpose or to a review of a wide spectrum of facts about nature. But science is more than a collection of facts, and teaching science requires more than presentation of information about the natural world.

If science education is important for all students, it must be for reasons other than the utility of science alone. It is always tempting, of course, to point to an end product. But by trying to rationalize the value of science education primarily in terms of what applied science or technology can accomplish, the goals of such education are placed on tenuous ground.

The primary goals of science education should be intellectual. What is required is student involvement in an exploration of important ideas of science. The mental stimulation and satisfaction of exploring one's environment, learning about its past and probable future, examining man's role in the scheme of things, discovering one's own talents and interests—these are reasons enough for the study of science, just as they are for the study of most disciplines. Science is one of man's major intellectual accomplishments, a product of the mind which can be enjoyed —not for its material fruits alone but for the sense which it provides of the order in our universe.

The Role of NSTA in Curriculum Development

The central purpose of the National Science Teachers Association is the improvement of science instruction at all educational levels. Commitment to this purpose requires NSTA to be concerned not only with curriculum development in terms of course content and learning experiences but, also, with instructional materials and methods, facilities and equipment, and teacher education.

The National Science Teachers Association takes the position that to be fully adequate the school science program:

1. Must start as early as kindergarten or first grade;
2. Must be articulated from one level to the next through grade twelve, or higher;

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3. Must encompass a full range of the contemporary knowledge and ideas which scientists employ;
4. Must result in understanding the nature of the scientific enterprise through direct student involvement in the processes of scientific inquiry;
5. Must involve the best that is known about child growth and development and the psychology of learning; and
6. Must be supported by first-rate staff, facilities, and instructional materials.

With regard to evaluation, the Association believes that this process should be closely tied to the stated objectives of a given curriculum. But goals should be stated independently of the problem of evaluation, and methods should then be sought to test the attainment of these goals. Where the evaluation of a given set of goals turns out to be difficult, this should not be taken as indicating a weakness in the goals but, rather, as a weakness in our knowledge of evaluation.

The National Science Teachers Association asserts its position that no single program can or should be designed for use in all or even a majority of the school districts of the nation. The Association believes in multiple efforts in curriculum development and will encourage and assist efforts involving creative and diverse approaches by many groups and agencies—local, regional, and national. Because of the need for leadership and guidance in the development of science curricula, the Association will strive to keep the total picture of science education in focus, to seek to identify the over-arching themes in science, to clarify the goals, and to establish criteria for sound curriculum development in science.

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